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RECLAIMING THE ATTIC

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THE HUBERT GROUP
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RECLAIMING THE ATTIC

FINAL REPORT PREPARED FOR
CANADA MORTGAGE AND HOUSING CORPORATION

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EXECUTIVE SUMMARY

The attic study, based on CMHC terms of reference, aimed firstly to examine whether in dwelling units it is economically more efficient to utilize the area under the roof for habitation and, secondly, to determine the technologies and the costs of the structures that would be suitable for providing the habitable attic.

The research started with the analysis of changes in household space needs and income through the various growth stages of families. By relating the space needs to age and income of head of households it has been shown that when dwelling units have a constant floor area, with no flexibility for expansion or reduction of space, large parts of dwellings are underutilized during the early years as well as later years of a family life. During the middle years when the family size is at the highest level these units are overcrowded. Therefore, it is desirable, and on a nationwide basis, more economical to have housing units which could grow with family income and needs, and which could later on be divided to two separate units, when the children leave and needs and income are reduced. The study has shown that the development of the attic is one of the least costly, and least disruptive alternatives for providing the needed flexibility in dwelling units.

Before the 1950's, with the stick built structures, attics were habitable, or could be finished to become habitable, if needed. With the introduction of the light weight prefabricated truss, with much lower cost and more speed of construction, the stick built attics have become less popular, and so, the area under the roof, traditionally used for habitation has become a wasted space. A short survey of attics in four major urban areas demonstrated the variety of attic spaces traditionally used in the different centres. The survey also revealed the current architectural trends towards higher-pitched roofs which would be very suitable for provision of the habitable attic.

The study proceeded with the determination of conditions necessary for a habitable attic space. It has been shown that to be habitable, an attic should meet certain architectural, structural and environmental conditions. It should provide sufficient volume and be amenable to provision of dormers and skylights. It should be structurally sound and provide for the installation of necessary insulation, air/vapour barriers and ventilation.

On the basis of the defined conditions for the habitable attic, a search for the determination of suitable attic systems was carried out. Different attic solutions exist in the market or can be combined from available systems or components, which meet the architectural, structural and environmental conditions necessary for a habitable attic. Various technological advancements in the last two decades have facilitated the design and construction of habitable attic structures. Specialized engineering services and industries can determine the characteristics of attic structures through computer analysis of slope and span of roof and design loads. Computer generated design drawings show cutting lists, size, type, and location of connections. With prefabrication and pre-assembly, of all or parts of the components, production and construction time has been reduced. New products such as Laminated Veneer Lumber or Parallel Strand Lumber, enable the economical use of low value species of wood with higher strength and smaller dimensions. Other products, such as the Stressed Skin Plywood Panels and Panels of plywood 'I' beams with integral rigid insulation, combine structure with sheathing, insulation and drywall in one prefabricated panel and so reduce construction time. These panels, when initially used for roof construction, enable the users to convert the area under the roof to a habitable space, at a future date, without the need for installation of insulation or drywall.

The combined results of these developments is the availability of various systems, or components, adaptable to attic construction, as well as increasing speed in the stages of design and construction of attics. Fourteen alternative attic structures were studied and evaluated in the study. These systems are basically variations of four different structural solutions. Within each structural group, they differ in terms of usable floor space and shape of the habitable volume; materials, type of environmental control, degree of prefabrication and cost. The fourteen alternatives were evaluated on the basis of these characteristics. Two systems were identified as being the most suitable at the present time. The truss with an integral floor, and the scissor truss on pony walls, referred to in the study as systems A and D respectively, meet the necessary conditions and are also more economic. System A is the least expensive and System D, although more expensive than B, enables the full use of the floor area. Systems D & E, both on pony walls, are the most efficient in terms of the use of floor area and cost per m^2 as they provide a 100 percent usable floor space. The panel systems

reduce construction time due to the integral insulation, vapour barrier and interior finish but they are presently much more costly and less readily available. Lack of adequate ventilation is also a problem in these systems. This evaluation, however, is only valid at the present level of demand and technological development. Changes in demand, prefabrication and availability of materials in the future will alter this evaluation.

The availability of structural systems for providing a habitable attic area will not necessarily result in the general acceptance of the concept by the public and the widespread use of these systems for roof construction. The public acceptance of the attic area as a potentially habitable space depends mainly on cost. To determine the economic viability of a potentially habitable attic a series of cost analyses were carried out to determine, firstly, if finishing a potential attic would be less costly than building an on-grade addition, and secondly, whether using the attic truss is economically more efficient than using the traditional light-weight truss.

Cost comparisons made between an on-grade addition to a bungalow, and the incorporation of an attic area of the same size, in the same bungalow, showed that the cost per m^2 of providing an on grade addition is $478.70 as compared to $402.37 - $420.28 for providing the accommodation in the attic. This does not include the additional cost of land for the on-grade addition. Moreover the cost of providing for habitation in the attic could be staged in two parts, the initial cost of providing an unfinished attic and the cost of finishing the attic at a later date, when needs arise and family income allows such an expenditure.

The cost analysis also showed that, if the cost of a bungalow with a regular lightweight truss roof is compared to the cost of the same bungalow, but with an attic truss, the total cost of the unit with the attic truss would be between 15-22% higher than the cost of the bungalow with the regular truss. For this additional cost, the bungalow with the attic truss would have the potential of finishing the attic and adding between 72-100% more to its floor area at a later date. The cost per m^2 of providing the accommodation in the bungalow is $524.26 compared to between $402.37 to $420.28 for providing the same area in the attic. As shown in the report, the two cost figures for the attic relate to a scissor truss on pony wall and an attic truss with an integral floor respectively.

While the cost of an attic truss is presently about twice as high as the cost of a regular truss, the difference in total construction cost, for providing a habitable attic, is only about 20%. However since builders and homeowners are not fully aware of the potential benefits of the attic truss, decisions are made on the basis of the cost comparison between the two systems; i.e., if the regular truss is half the price of the attic truss, that will be the system chosen.

But if the cost comparison is broader and the cost of the roof is analyzed as a percentage of total construction cost, together with the benefits arising from the potential of a habitable attic, then a more rational decision can be made.

As stated earlier, the research carried out for the selection of the attic structures indicated that the limited use of attic spaces does not result from in existence of suitable systems. Both the systems, and the engineering and manufacturing expertise exist across Canada to provide the suitable structures for habitable attics.

If, as the study has shown, the systems or components of systems exist in the market, and, the cost analyses are also favourable, the obstacle to the widespread use of attics cannot be a technical problem. The conclusion of the present study is that a limited cost comparison rather than a broader cost/benefit analysis is the main obstacle to the use of attics in dwelling units across Canada. If this broader framework for evaluation is adopted the economic efficiency of the attic truss as compared to the regular truss will become evident. In large scale housing developments, where many tens or hundreds of units are built the economic advantages are considerable and the use of the attic for part of the accommodation will increase the numbers of dwellings that could be built within a specific budget. An increase in demand will result in more efficient technical solutions for the habitable attic and lowering of costs, which will ultimately render the attic solution an even more economical alternative. An analysis of changing price - relative to increasing demand for attics has been carried out and presented in the study to support this argument. It shows that even at present levels of technological development the costs of the attic structures fall with increase in demand and will be reduced by 30% if 500 attic units are produced. In other words, the economic comparisons presented would be more favourable for the attic solutions if the foreseen increase in demand and the corresponding decrease in cost is considered.

INTRODUCTION

This report summarizes the results of a research study carried out for CMHC on the potential of the attic as a viable area for expansion in homes. The intention is to, firstly, show that it is economically efficient to utilize the area under the roof for habitation and, secondly, to determine the technologies and costs involved in achieving this potential.

The necessity for the study originated in studies which revealed that user satisfaction was directly related to flexibility and the possibility for expansion in homes; that attics had historically been an area of expansion; and that with the introduction of the prefabricated truss in the 1950's, the attic had gradually disappeared. The light weight prefab truss, while reducing amount and size of wood members, increases construction speed, but on the other hand results in unusable ventilated attic space. Considering factors such as technological innovations in composite structural members, acceptance of steep roofs as visual symbols of domestic life, and improved windows and skylights, CMHC intends to explore the potential for the reintroduction of the attic space in low rise residential buildings.

The present study addresses this general objective and, as defined in the Terms of Reference, aims to:

- identify types of attic space traditionally built;
- define technological advancements related to provision of attics;
- assesses the limitations of current technology in achieving speed and efficiency; and
- develop solutions and approaches to overcome these limitations

In Section One of the report, the changing needs of home owners in different economic and life stages are analyzed, followed by a definition of the potential and advantages of a habitable attic space to cater for these needs. In this analysis, the needs of the home owner as well as the opportunities for the builder, the developer and the local government are discussed.

Section Two summarizes the results of a survey that has been carried out in four major cities to define the types of roof structure, and characteristics of the attic space before the introduction of the gang-nailed truss. A brief description is also given of the structural arrangements of the typical roof framing system commonly termed "cut-roof" attic.

In Section Three the architectural, structural and environmental criteria for a habitable attic structure are developed. The architectural criteria are based on the acceptable height of the attic space in relation to width of the unit and roof slope. The structural criteria are developed on the basis of the analysis of the advantages and limitations of the gang-nailed prefab truss and the required structural performance standards. The environmental criteria are defined in relation to insulation, air and vapour sealing and ventilation.

The structural solutions developed to respond to these characteristics are presented in Section Four. Our findings corrected some of the considerations put forward in the terms of reference regarding the assessment of limitations of current technology and developing solutions to overcome these. It has been found that numerous systems are available that can provide a habitable attic and the engineering and manufacturing expertise exist to design and produce these structures if the demand exists. Fourteen such systems are shown in Section Four. Each alternative roof structure is analyzed in terms of its structural performance and type of attic space provided. In order to facilitate comparison and a general evaluation of the various systems, a typical housing unit with specific spaces and area requirements is defined and the habitable attic spaces for each alternative is described and shown on the typical drawings.

In Section Five, a cost analysis is carried out for the different attic structures developed. The cost of providing the required living space in the typical unit is calculated for two alternative attic structures and compared with the cost of providing the same living area without using the attic space. An analysis is also presented to show how the cost of an attic structure will be reduced if increasingly more quantities are produced.

Concluding remarks on the results of this study are given in Section Six. Here, a brief statement of the problem and the opportunities offered by the habitable attic space, are followed by a discussion of the results of the cost analysis and the need for encouraging a broader economic outlook in evaluating the habitable attic.

1. CHANGING NEEDS AND THE POTENTIAL OF A HABITABLE ATTIC SPACE

1.1 The Home Owner

Housing needs are determined by a variety of factors. Household size and structure, socio-economic status, change of jobs and preferences for special locations or neighbourhoods are among the factors which influence and change the housing needs of households. Some of these transformations are only possible by the change of location and moving into a new area and a new housing unit. Others can be accommodated through the expansion or reduction of the habitable area available to a household.

Families respond to their perceived needs on the basis of the means and possibilities open to them. Assuming that location and neighbourhood preference remain constant for a family through a good part of their life cycle, household size and in most cases, economic status of the family change, necessitating transformations in the available habitable area. In such cases the available options for the family are the building of additions or, if possible, expansion within the existing shell.

If, due to changes in economic status or location, the family leaves the dwelling unit, the evacuated space has to cater to the needs of a new family and a new set of space requirements. Again the flexibility of the unit becomes very important.

When the household size reduces again after the children leave home, the possibility of renting a part of the home that is not being used, while remaining in the same familiar neighbourhood, becomes very attractive. Many two person or one person elderly households remain, in large, mostly unused houses, for many years due to their reluctance to leave familiar surroundings and neighbours.

On the other hand, the division of these houses into two units, one of which could be rented out or used by other members of the family, is often very difficult. Due to the layout of these houses, this division would involve considerable cost, disruption and unsatisfactory location of various activity areas within the units.

A separate dwelling unit in an attic space, previously designed for possible separation, can be used in a multitude of ways. The flexibility of such an arrangement would enable it's use for auxiliary activities as well as for extended family living or renting out.

Fig 1, developed on the basis of the above argument, shows the changing space needs of a family through their various growth stages. To examine the validity of the relationship presented in Fig 1, data on household income and number of persons per household according to age of head of household were obtained from Statistics Canada 1981 Census. This data is presented in Figures 2 and 3 and verifies the theoretical relationships developed and shown in Fig. 1. The advantage of a flexible dwelling unit versus a fixed space unit in terms of reducing the surplus area is shown in this figure. If one applies this argument to dwellings across Canadian urban areas it will be evident that large portions of existing dwellings are under utilized due to lack of flexibility.

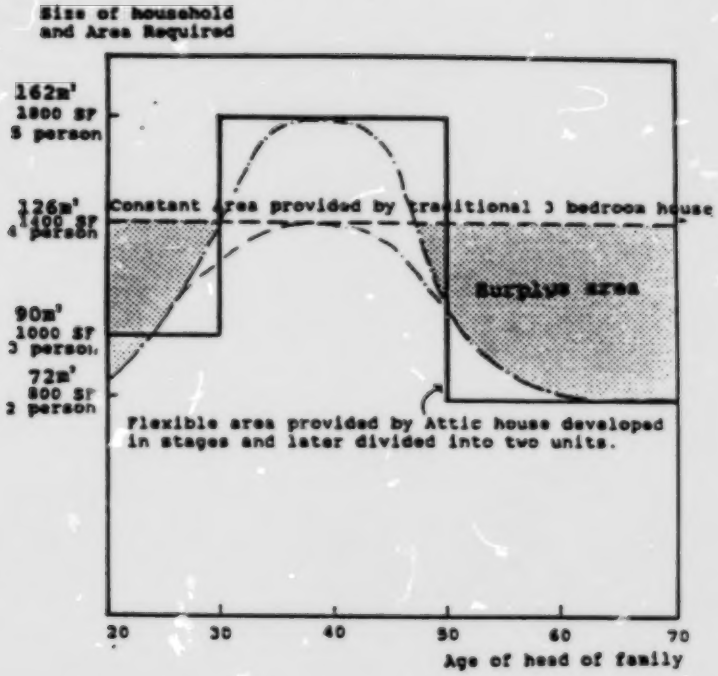


Fig 1 - Theoretical relationships between Average Area of dwelling needed for each household size and Age of head of household.

Note: The curves show the theoretical relationship between age of head of family and dwelling area required. The shape may be different according to ultimate household size and standards of area per person. However the basic relationship remains the same with maximum demand for dwelling space occurring when the head of household is between 30 to 50 years old. Around the age of 50, the household size and correspondingly the required dwelling area are reduced. It is interesting to note that there is a more or less similar relationship between family income and age of head of household, giving more strength to the argument for the divisible attic space. When family income, as well as area required, are reduced around the age of retirement, the option of renting out a part of the home becomes very attractive.

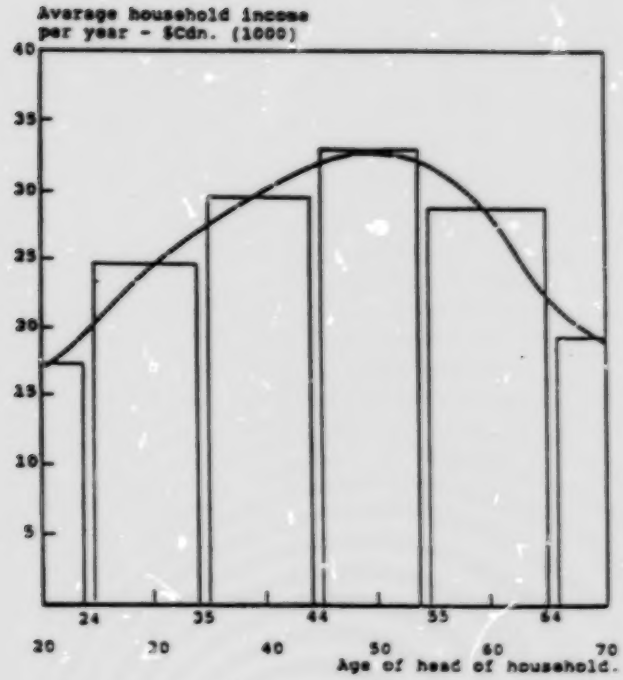


Fig 2. Relationship between Age of head of household and average household income in Canada - 1981.

Age of Head of Household	Average Household Income per year - $ Cdn.
15-24 years	17,349
25-34	24,627
35-44	29,414
45-54	32,929
55-64	28,532

Average household income/year by age of head of household in Canada - 1981.

Source of data: Statistics Canada - 1981 census.
Table no. SPY - 81B93

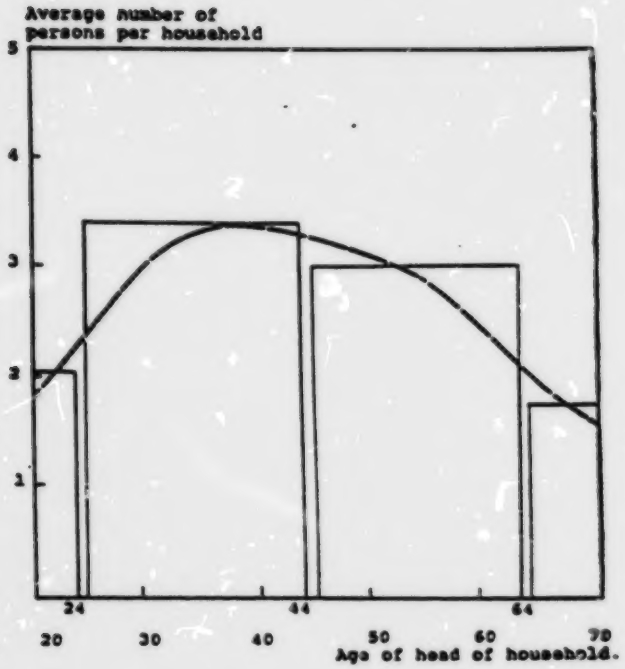


Fig 3 - Relationship between Age of head of household and average number of persons per household in Canada - 1981.

Age of Head of household	Average Number of persons per household
15-24 years	2.1
25-44	3.3
45-64	3.0
65 & over	1.8

Average no of persons/household by age of head of household in Canada - 1981.

Source of data: Statistics Canada - 1981 census, Table no. SPH 81B18

Thus, the existence of potential for change in the dwelling unit is both socially and economically important for the homeowner. Theoretically, the options available for this change are expansion in the basement, in the attic or building of additions to the dwelling unit. Building additions is always more costly as shown on the cost analysis studies in Section Five. Moreover in some moderately sized urban dwellings, especially new townhouses, lot size and configuration do not easily allow for such an expansion. Extensions also disrupt the continuity of the exterior envelope, with potentially serious consequences for the integrity of the structure.

Development of the basement is the other alternative which is ideal in cases where the basement has good natural lighting. However, in some situations where the basement does not have enough lighting or an acceptable exterior orientation, it can be developed to contain only auxiliary areas such as recreation rooms, storage, etc., and it may not be suitable for living and bedrooms for other than interim periods.

The development of the attic offers the most acceptable situation. A dwelling unit with an unfinished attic space which has the potential of being developed into additional living or sleeping quarters, and later divided into a separate unit has many attractions. Environmentally, lighting and views are good in an attic. A habitable attic means a more efficient use of the space provided by the structure.

Another argument in terms of needs of the homeowner relates to young, first time buyers with no children and a modest income who may prefer an unfinished or semi-finished attic space to an already finished two storey house if it means lower mortgage payments. The attic can be finished in later years when the need for more space arises and the economic means for expansion are available. If the family chooses to continue to live in the unit when the children leave, an attic that was initially designed to have separate stairs and entrance areas would prove ideal as a unit for renting out. In conclusion, the homeowner would find an unfinished or semi-finished attic space attractive, both economically and in terms of space requirements. Lower initial cost and mortgage payments, higher resale value when the attic is finished, numerous possible uses of the attic, and the option of separation into another dwelling unit are among the attractions of the habitable attic space.

1.2 The Builder/Developer

A habitable attic space that could be provided at reasonable additional costs will be attractive to the building industry in a number of ways.

Because of lower initial costs of an undeveloped or semi-developed attic in comparison to a fully finished floor, the number of first time buyers who could afford to purchase will increase. Cost studies, presented in Section Five of the present report, show the cost differences. The estimated cost for a finished bungalow of 100m², with three bedrooms is $52,426. A 1 1/2 storey home with 60m² of finished space and a potential unfinished attic area of 40m² costs $41,770. The attic can be finished at a later date with an additional expenditure of under $8,000. The cost per m² of these two alternatives will be $524 and $495 respectively. If as shown in Section five, an attic structure with a pony wall is used the cost per m² of the finished house with the attic will be even lower at $429, corresponding to a saving of about $100 per m² as compared with the bungalow with the regular truss. This difference in cost allows for an increase in the first time buyer market where, as already established, there is a preference for single family or townhouse living versus multi-storey condominiums. While comparability of the above mentioned housing units may be questioned, the fact that the attic option can provide the same living spaces at a future date justifies the comparison. The purpose of such a comparison is to show that a segment of the population, previously unable to enter the housing market, will now be able to afford single family living by paying less at the time of initial purchase. The resulting expansion of the market is to the obvious advantage of the builder/developer.

As discussed and shown in the cost analysis section of this study a usable attic space within a dwelling reduces the cost per square meter of habitable area in comparison with a dwelling unit of the same area with standard roof. This is another added advantage to the developer who can now 'sell ' the space previously wasted, with minor additional costs.

Other segments of the market who will be attracted to the attic house are mature households with children in late teenage or young adult years. The possibility of having separate living quarters in the attic for adult children and later renting out these premises is very attractive. The building industry will benefit here again by providing this flexibility, and catering to the needs of mature households who may not wish to leave their familiar surroundings and move to smaller units.

In conclusion, the building industry can benefit not only from the expansion of the first time buyer market, but will also benefit from market diversification. By sensitivity to transformations in demand due to cultural and demographic characteristics of the population, the industry will be able to cater to changing needs of households with different cultural and life cycle requirements.

1.3 The Municipalities

The flexibility offered by the attic house provides a potential answer to many of the housing concerns of local governments.

Young first time home buyers will be able to afford housing at an earlier stage, providing a tax base in the community and the possibility of maintaining education and community facilities.

The potential for separation of the attic spaces for renting out or accommodating adult children will increase the stock of rental units while at the same time enabling elderly home owners to remain in their familiar surroundings and neighbourhoods.

A smaller footprint for the building which will result from development of an unfinished attic in comparison to making a horizontal addition to the house, may be advantageous in terms of less bulk and greater exterior space and overall amenity.

In conclusion of section one, the points presented can be summarized to two main areas which form the central arguments of the study, and which are the basis of the sections that follow.

As argued earlier, it is desirable to have housing units which could grow with the family and its income. One potential area for accommodating this growth is the attic space. However, with the standard roof truss, the area under the roof is not usable for habitation. Therefore, the first argument is that using this area for living is a more efficient use of space, and therefore it is necessary to examine the structural solutions for roofing which could provide an attic area that could be used for habitation.
The Second point put forward above is regarding the flexibility that a "potential" attic space provides for the homeowner. In some cases, taking full advantage of the flexibility offered by the potential attic, might require relaxation of certain municipal regulations, regarding the renting of part of a dwelling unit to another individual or family. However, in many other cases, as argued earlier, this flexibility is possible within the existing regulations.

The present study, therefore, concentrates on the first of the above arguments i.e., cost efficiency of a usable attic space, and attempts to examine the various structural solutions for providing this space and the cost efficiency of these solutions.

2. SURVEY OF ATTIC STRUCTURES BUILT BEFORE THE INTRODUCTION OF THE LIGHTWEIGHT TRUSS

2.1 Use of Attics in Existing Dwelling Units.

A short survey of attic structures in four major urban centres including, Vancouver, Calgary, Toronto, and Montreal was carried out by the research team. The purpose of the survey was to determine the types of attics in the past and their structural characteristics, as well as the current trends of domestic architecture in the various regions and their effects on the provision of the habitable attic.

In all the four centres visited there were examples of dwelling units, built before the introduction of the truss, with parts of the accommodation provided in the attic. In row housing and smaller units this consisted of two bedrooms and possibly a bathroom in the attic. In larger units the attic space was usually used for storage or secondary accommodation. In Montreal, one of the popular architectural styles, the " Maison Canadien" consisted of one storey plus a dormer-windowed attic above in the front of the house but with a full two stories at the rear. Although this form deviates from the typical attic space it is still considered an attic.

Fig 4 shows the various types of attic structures built in Canada prior to the introduction of the prefabricated roof truss. Photographs on pages 22 to 27 show some of these structures in actual buildings.

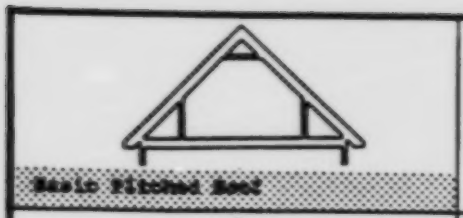
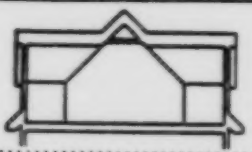
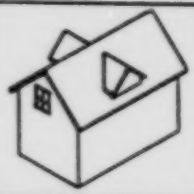
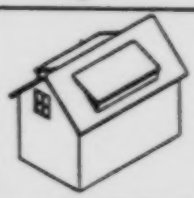
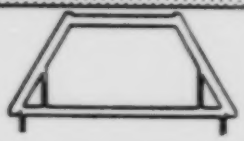
 Basic Pitched Roof		Typical Across Canada	Single family Duplex & Row housing
 Pitched Roof Gable Dormers		Typical Across Canada	Single family Duplex & Row housing
Pitched Roof Shed type dormers		More common in Toronto & Western Canada	Single family Duplex & Row housing
New England Saltbox		Common in Quebec	Mostly single family or Duplex
 Mansard		More common in Quebec	Single family
Double Hip		More common in the East	Single family
Gambrel		More common in Quebec	Single family

Fig 4 - Traditional attic types found in buildings built prior to the introduction of the lightweight truss.

2.1.1 The Basic Structural Characteristics of Attics Built before the Introduction of the Lightweight Truss

The structural arrangement of the traditional roof framing system, prevalent before the lightweight truss, and commonly termed "cut-roof attic", is shown in Fig (5). The primary structure spans from outside wall to outside wall as a 3 - hinged arch with straight segments. The rafters form the typical 3 - hinged arch. The inclusion of cellar tie and pony walls reduce the effective rafter span for local bending.

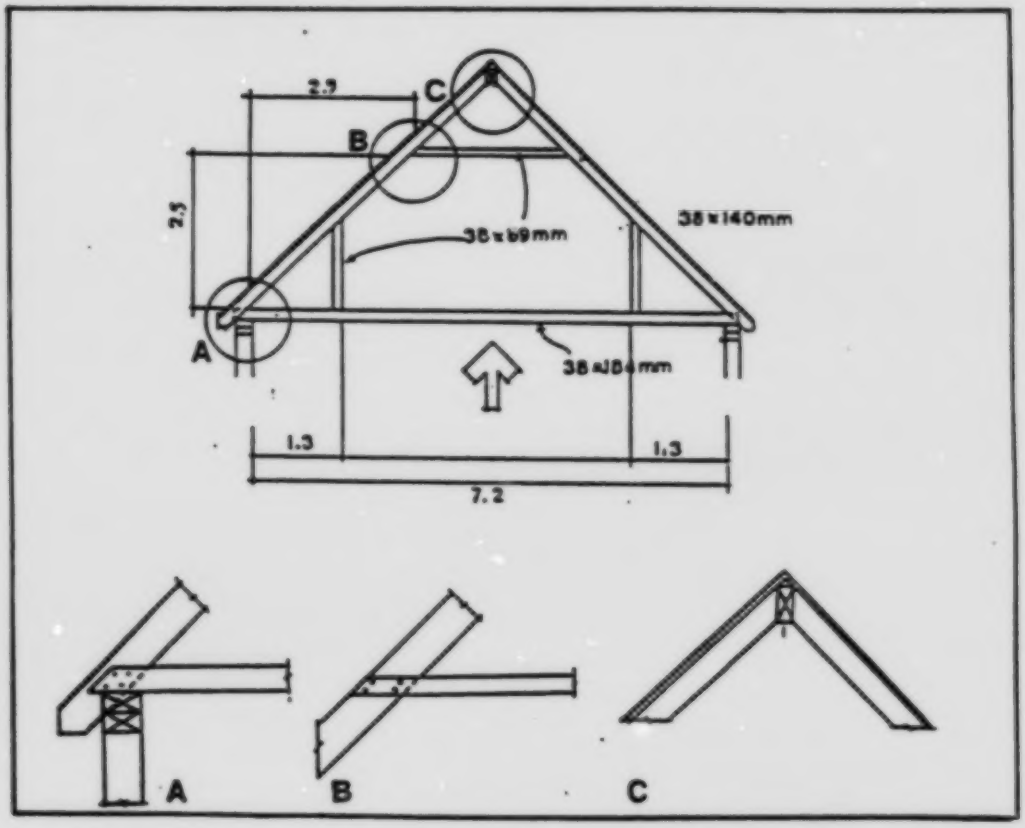


Fig (5) - The "Cut Roof" Framing System

More information on the structural characteristics of traditional attics is presented in Appendix 2.

2.1.2 Environmental Considerations in Traditional Attics

Due to low energy prices in the past, insulation of buildings was not as critical as it is today. For attics not intended for habitation no insulation or weather proofing was required in the roof and walls. However, often some type of insulation material was placed between attic ceiling joists for some heat resistance and to stop cold drafts.

In habitable attics, insulation and weather proofing was the exception. When insulation was used it was often primitive, composed of any available materials such as newspapers, shredded paper, wood shavings and saw dust. Cavities in the wood frame and roof were filled with these materials. In more recent years, batt/blanket or loose fill insulation was used but it was not common to fill all the wall stud spaces with insulation because of low cost of energy.

In traditional attics, air-vapour barriers were not installed, nevertheless, many older houses have remained immune to the problems caused by air and vapour movement because the structure of the house dissipated water vapour quickly. This rapid dissipation was due to the many openings and cracks in the construction that allowed natural ventilation and free flow of air through the structure.

2.2 Current Trends Affecting the Reintroduction of the Habitable Attic.

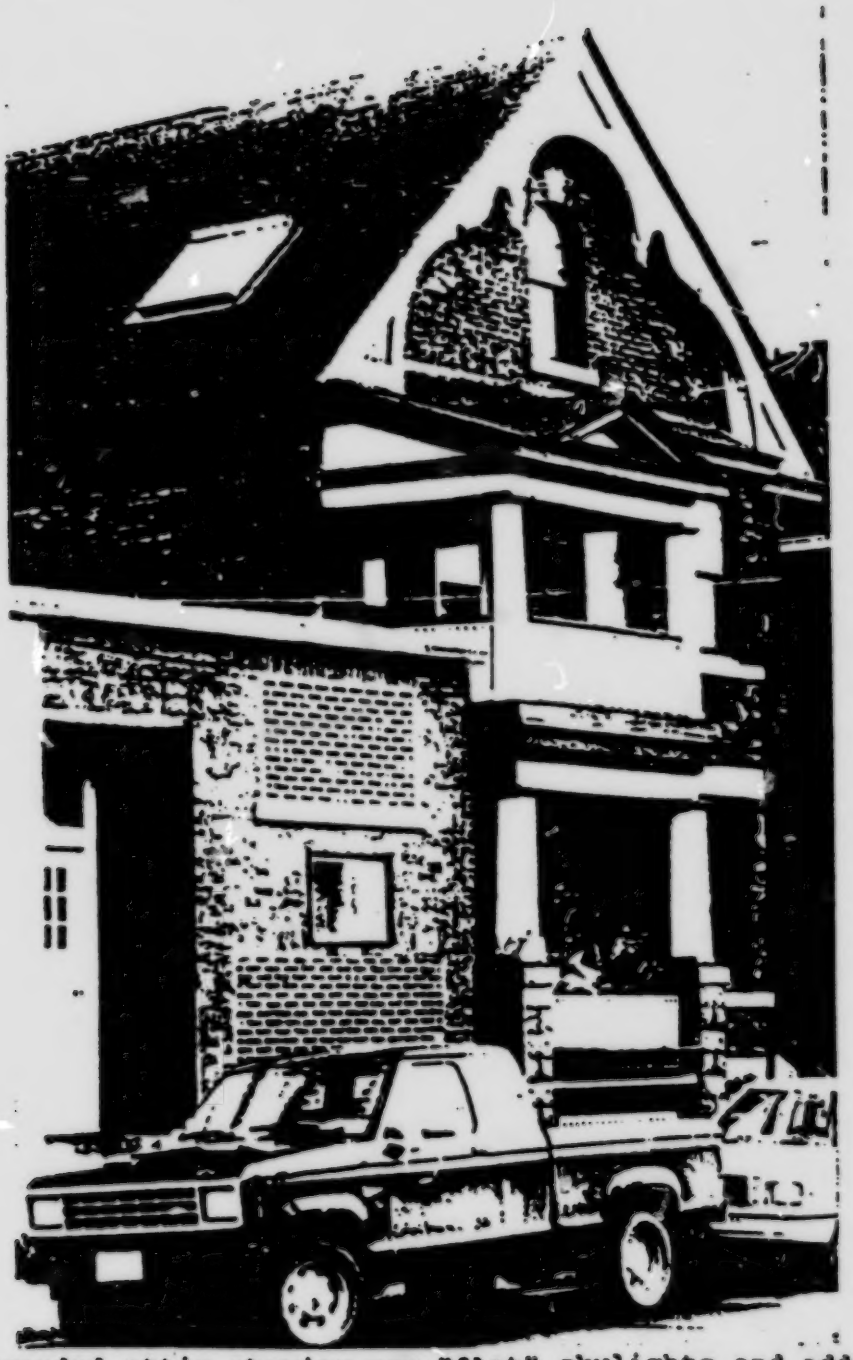
The current architectural styles in all the major centres visited provide the opportunity for the design and development of habitable attic spaces.

One important trend in all these centres is the incorporation of steep roofs in the design of the building bulk and exterior elevations as options for the provision of high volumed living spaces within the dwelling. In these cases the attic has become an integral part of the dwelling unit and provides the space for bedrooms, dens and bathrooms. Technological innovations in skylights and custom windows together with unusual roof shapes have resulted in interesting and bright spaces. Some examples of these new developments in skylights and dormer windows are shown in Appendix 1. As shown, it is possible to install skylights and dormer windows to fit attics with different design requirements.

An example of this trend, towards steep roofs, is seen in Quebec in the revival, since early 1970's, of the traditional style of the "Maison Canadien", where already pre-manufactured trusses for attic construction are being used. This truss has all the advantages of the regular truss for speed of erection. It is usually heavier than a non-attic truss, but is delivered to the site, lifted to the roof and erected in the same way and at the same speed.

Another trend in new homes is the provision of attics over the double garage. This space is usually given to games rooms or dens.

A traditional 1 1/2 storey brick house with an attic space above the second storey, which is partially in the roof.



Upgraded attic showing new "flat" skylights and additional ventilation roof jacks.

Brick clad 2 1/2 storey home under renovation. Attic is formed under a gambrel style roof.

Row houses with mansard roofed attics.

Row houses with habitable attic spaces

A mansard roofed house with gables and mansard dormers, converted to multiple suites.

3. ARCHITECTURAL, STRUCTURAL AND ENVIRONMENTAL REQUIREMENTS FOR A HABITABLE ATTIC STRUCTURE.

In order to develop alternative structures for a habitable attic, specific requirements have to be defined to form the basis for selection and evaluation of these alternatives. Architectural, structural and environmental requirements have to be considered as follows:

3.1 Architectural Design Requirements

The two design factors that define the attic space in a dwelling unit are the roof slope and the width of the unit. These two factors, in combination, dictate how much of the attic space is habitable and which areas can be used only for storage.

Part 9 of the National Building Code (NBC) has specific regulations relating to the use of the attic space.

According to these standards, for an attic to be used for living or dining areas, at least 75% of the floor area should have a minimum height of 2.3 m. For bedroom spaces, at least 50% of the floor area should have a ceiling height of 2.3 m.

The areas which have a ceiling height of less than 1.2 m are not included in the measurement of the habitable area (Fig. 6). However these spaces can be used for storage.

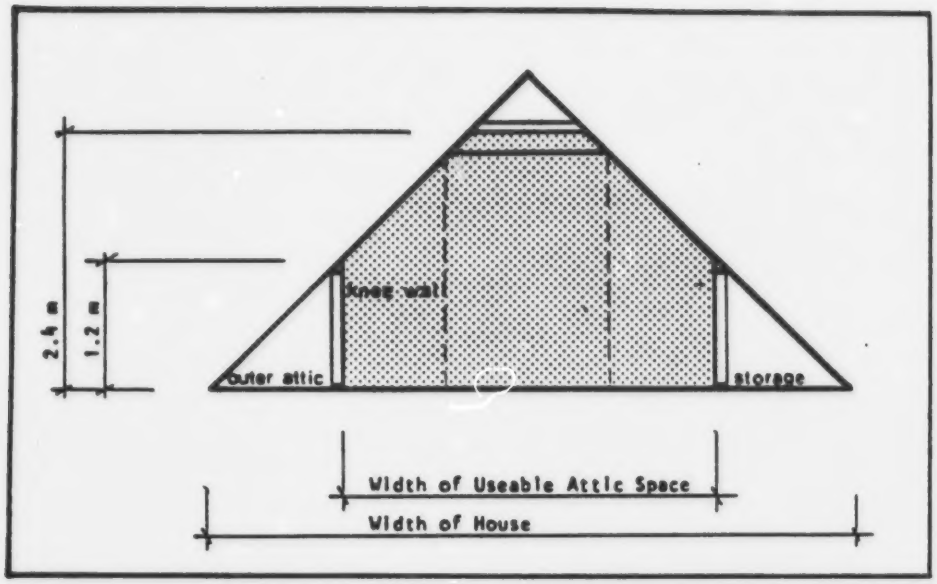


Fig. 6 - Width of useable attic space and storage areas.

On the basis of the two above mentioned height requirements the relationships between the usable attic space, roof slope and width of the housing unit, for some typical cases is shown in Fig 7. The shaded area in Fig 7 relates to those combinations of roof slope and width which do not produce the necessary ceiling height to allow the provision of any habitable area in the attic space and can only be used for storage. All the other combinations shown are habitable if the necessary structural and environmental conditions are met. Fig 7 presents the basic type of attic structure; however if, as discussed in sections 4.2 and 4.3 of this report, other solutions such as structures with pony walls are considered, then the roof slopes shown in the first two rows in Fig 7 can also be used for the habitable attic structure.

Based on the above discussion, the following conditions have to be considered in the development of the alternative attic structures to be proposed:

a. For typical house widths up to 10.8 m, classic attic structures with a roof slope of less than 30° or 7 in 12 do not provide the necessary height for a habitable attic space.

b. Roof slopes of 35°, 40°, and 45° can provide the necessary attic height for all the typical house widths except the 6.00 m. width, which cannot have a habitable attic space.

c. As shown below, for the basic attic structures shown in Fig. 7 the most efficient roof slope is the 45°, or 12 in 12, - slope which provides for an attic suitable for bedroom areas for units with a width of 7.2 m or more. It provides living room areas for width of 8.4 m or more.

Width of House	Slope of Roof 25°	30°	35°	40°	45°	Efficiency Ratio of Attic Floor to Dwelling Floor Below
8.4			5.9	5.4	5.1	58-69%
9.6		5.4	6.1	6.6	7.0	56-73%
10.8	5.6%	6.5	7.2	7.8	8.3	60-77%

Width of Useable Attic Space

If, however, alternatives with pony walls are used, lower roof slopes will also be possible. These are the most efficient systems in terms of efficiency in the use of floor space. This point will be further developed in Section Four of this report when the various alternative roof structures are discussed.

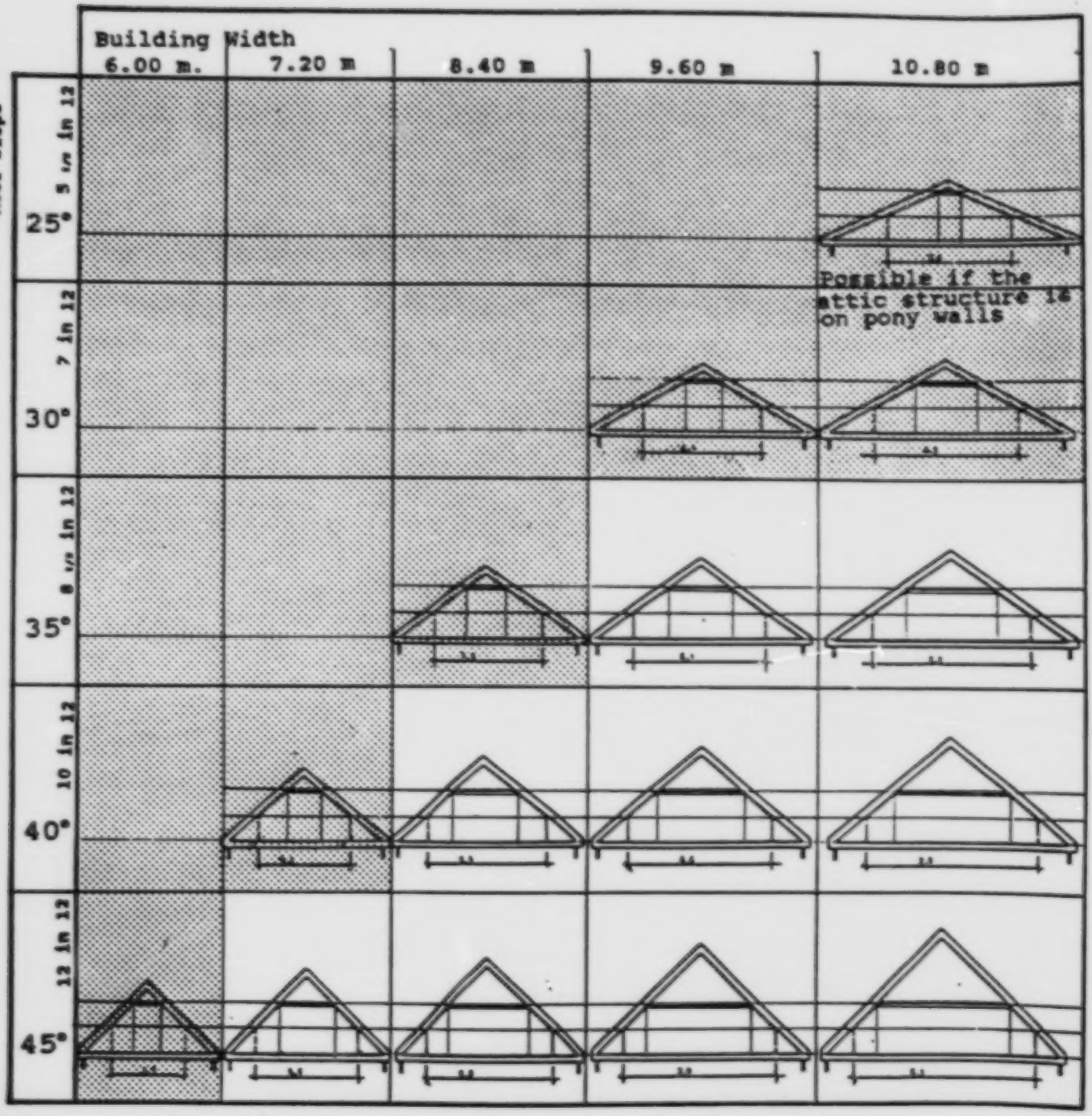


Fig 7 - Relationship between roof slope, width of unit and habitable attic space.

3.2 Structural Design Requirements

The purpose of any structural system is to ensure that the building has enough strength and stiffness to withstand any forces that may be experienced during the life of the building. Presently single family houses can be designed to meet two differing sets of criteria in Canada, covered in Parts 4 and 9 of the National Building Code (NBC). Essentially all low-rise residential buildings can be considered under Part 9 of the National Building Code. The structural clauses in this part provide for non-engineered solutions. However, house structure, or certain parts of the house structure, are often designed to meet the requirements of Part 4 of the NBC, when for some reason, it is considered that the Part 9 provisions do not adequately cover the issue under consideration. This is generally termed an "engineered" structure. Thus, for the selection and evaluation of structures suitable for providing a habitable attic space the following conditions will have to be met:

a. For the attic solutions considered in this report, even though they are for buildings which generally fall into Part 9 category, the roof attic structures should be engineered and meet the requirements of Part 4.

b. The attic structures should be designed to withstand various loads in the form of dead loads of the components themselves, snow and wind on the roof, and occupancy loads on the attic floors.

c. Each structure has to be designed to withstand the specific snow load requirements of a given geographical location together with the building's particular exposure, roof shape, adjacency to other structures, etc.

d. A load bearing wall supporting the ceiling joists at or near their centres below the attic floor reduces the span. If there is no interior wall, the bottom cord of the truss would have to be deeper in order to carry attic floor loads. This would result in higher costs but provides more flexibility in planning the floor below the attic floor.

3.3 Environmental Design Requirements

The quality of environment within a dwelling unit depends on proper insulation, air and vapour barriers and ventilation. Therefore, in the design of the habitable attic structures, specific environmental requirements have to be met.

3.3.1 Insulation

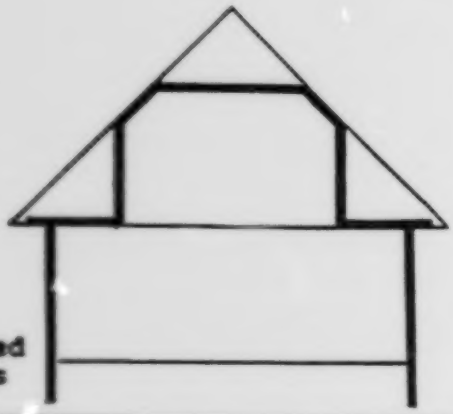
Walls and ceilings are insulated to minimize heat loss or gain through the wall or ceiling. The materials used for insulation can vary, but in each case a material is chosen to trap air and create an insulating blanket. These can be fibreglass, mineral fibre, rigid polystyrene, blown fibrous materials, foamed in place insulation or other plastic materials. The most appropriate material for any particular application should be selected based on cost, availability, and ease of installation as well as insulation value.

For finished attics or attics intended to be finished into habitable space the following conditions have to be considered for insulating the structures:

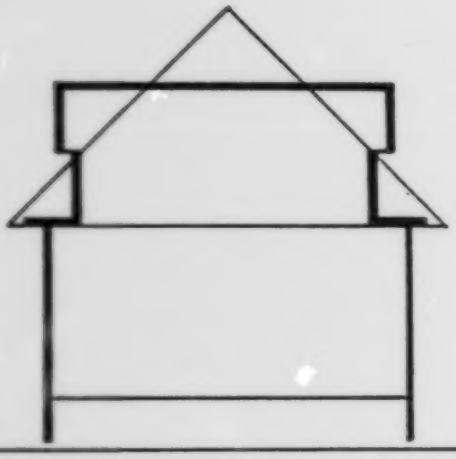
a) Batt or rigid foam materials should be applied to the outer attic floor, (i.e. the floor beyond the habitable space but under the roof), walls and ceilings to reduce the total space to be heated, or conditioned, to that intended for habitation. Space intended for storage should be assumed as habitable. Dormers should also be fully insulated. (Fig 8)

b) Insulation R values for outer attic floor and attic ceiling should be the same as required for ceilings.

c) R values for the end walls and knee walls should be the same as those required for walls.



a. Insulation should be applied to outer attic floor, walls and ceilings.



b. Dormers should be fully insulated.

c. Space intended for storage should be assumed habitable and be insulated.

Fig 8 Insulating the habitable attic area

d) R values for the short section of rafters connecting the knee wall and attic ceiling depend on the slope; for roof slopes greater than 60° wall R values are to be used and for slopes less than 60°, ceiling R values should be used. So for typical attic slopes of 45°, ceiling R values should be applied. But for structures such as the gambrel, where the slope of the abovementioned rafters is more than 60°, wall R values are used. (Minimum R value requirements for specific geographical regions are contained in local building code and energy guidelines.)

3.3.2 Air and Vapour Barriers

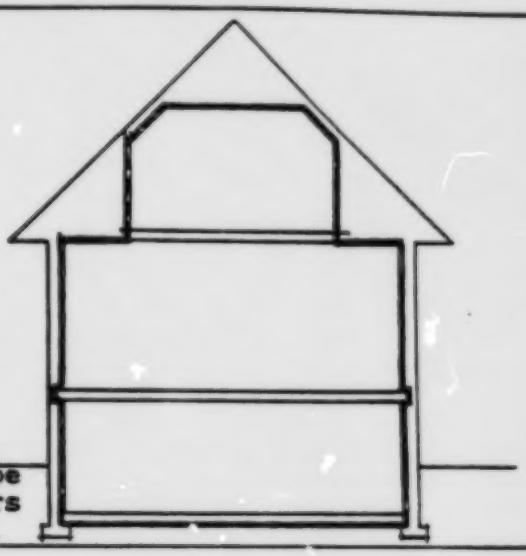
A vapour barrier prevents moisture transfer from the inside of the house, through the walls and ceilings. An air barrier prevents air movement through walls and consequent condensation of moisture in the wall or ceiling. Various combinations of materials such as Polyethylene film/sealant, drywall/vapour proof paint, gaskets around electrical outlets, foam insulation around pipe penetrations are used as air and vapour barriers.

Since, in most cases, the same procedures are used for application of air and vapour barriers the following conditions have to be met for both systems in finished attics or attics intended to be finished.

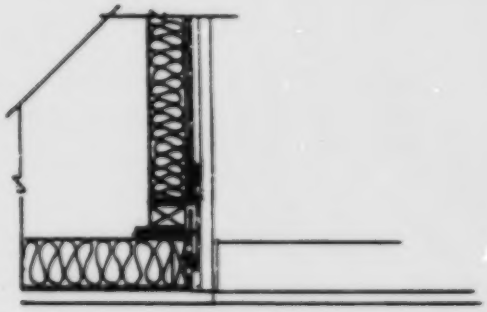
a) Finished attic space or attic space intended to be finished should be protected by a vapour/air barrier applied on the warm side of the insulation. (Fig. 9a)

b) Where the barrier is attached to insulation material, special care should be taken at the joint of the outer attic floor and at the joint of the attic ceiling with the addition of a strip of polyethylene, caulked at the edge. (Fig. 9b)

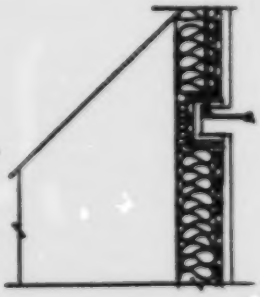
c) Where there are electrical outlets and pipes in the knee walls, they should be placed at the warm side of the vapour barriers. (Fig. 9c)



a. Air/vapour barrier envelope in an attic with no dormers and no window box storage.



b. Air/vapour barrier at joint of outer attic floor with knee wall.



c. Electrical outlets on knee walls should be placed on warm side of air/vapour barriers.

Fig 9 Installing air/vapour barriers in attics

3.3.3 Ventilation

Ventilation of attic spaces has traditionally been provided to minimize moisture levels in attics. When the roof is ventilated it is termed a "cold roof" as shown in Fig. 10a. Various types of vents can be designed for ventilation of attic spaces. These include soffit vents, gable vents, roof vents, ridge vents, turbine vents and power vents.

Recent advances in building materials have resulted in the production of roof systems which combine the structure, insulation, air-vapour barrier and interior finish. These roof panels are completely foam filled and do not allow for ventilation and air circulation. Such roofs are termed "hot roofs". (Fig. 10b) Many of these systems are not in widespread use and further research is necessary to evaluate their performance in extreme weather conditions.

For roof options which do allow for ventilation, the following conditions have to be met in the design of the ventilation systems.

a) All concealed spaces in wood frame construction should be ventilated.

b) Cross ventilation should be provided at the eaves/soffit and ridge or at gable ends.

c) Because of the variety of forces at work, attic ventilation requires a system of several vents. (Fig. 11)

A flow of air can be achieved with various combinations of soffit and roof vents. The most efficient systems for houses is one using an uninterrupted series of ridge vents, in conjunction with an uninterrupted series of soffit vents.

In this combination, the ridge vents will operate as outlet vents in the negative pressure area regardless of the wind direction. The soffit vents, placed on opposite sides of the building in the eaves, will function as intake vents.

When the combination of ridge and soffit vents is not possible, outlet vents may be installed on the roof surface near the peak or high in the gable ends. Vents installed on the roof surface near the eaves or low on the gable ends will provide for air intake.

An equal area of high and low vents will provide the best results.

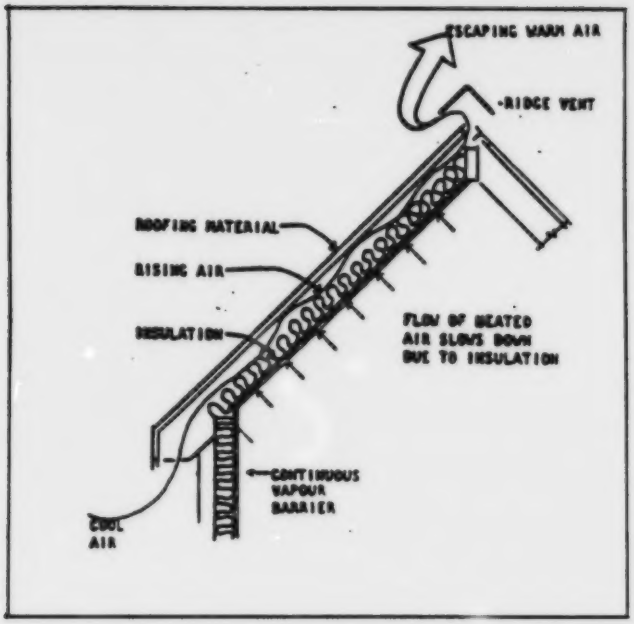


Fig 10a - Cold Roof

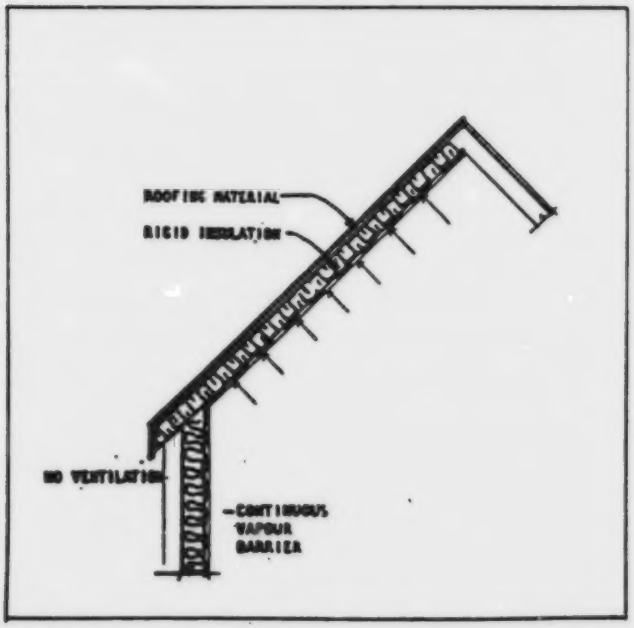
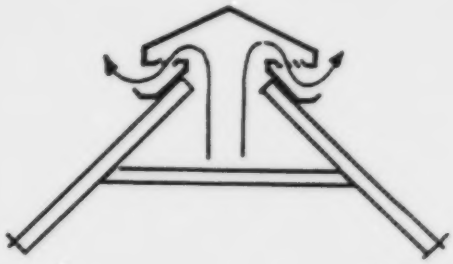
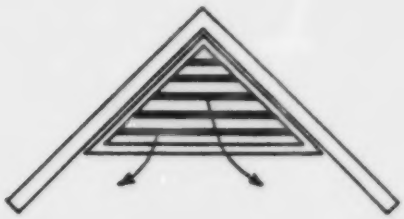


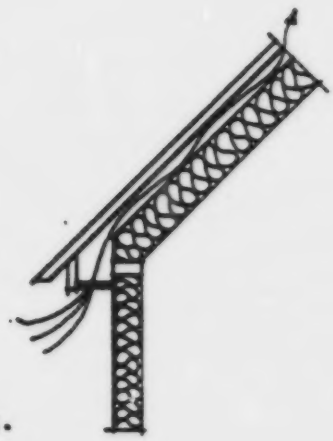
Fig 10b - Hot Roof



a. Ridge vents in combination with eave vents provide effective attic ventilation.



b. A system of gable vents combined with eave and ridge vents result in effective air movement.



c. Soffit roof ventilation.

Fig 11 - Attic Ventilation requires a system of several vents.

4. ALTERNATIVE HABITABLE ATTIC STRUCTURES

On the basis of the architectural, structural and environmental design requirements mentioned earlier, a search for the selection and evaluation of suitable attic structures was carried out. The purpose of this part of the study was to describe the systems, or components of systems, currently available in the market, and to identify the advantages and disadvantages of these systems. Fourteen different attic structures have been identified considering the requirements already discussed. In summary, the suitable attic system should:

- provide the necessary volume for habitation
- be structurally sound
- provide a satisfactory environment
- be economical in terms of materials used
- be factory assembled, as much as possible
- provide for easy installation of services
- be light weight
- be fast to install
- be cost effective

The systems identified all satisfy the above requirements, although they may differ in terms of materials, structural behaviour, availability in the market, and cost. The characteristics of each system is described in the following sections.

4.1 Types Of Attic Structures

Fourteen different alternatives have been identified and presented in four different groups in Figs. 12 to 15. The grouping is based on the structural behaviour of the systems but the alternatives in one group may differ in terms of materials, type of architectural space provided and insulation materials. For example the alternatives shown in Fig. 14 are all based on the same structural system but they differ in terms of materials used. Some employ the more common materials, such as flat laid 2x4's or plywood web rafters, while others use the more newly developed materials, or combinations, such as the stressed skin plywood panels or plywood 'I' Beams with integral rigid insulation.

Most of the systems shown can be produced by local manufacturers in the various provinces. Based on the required slope and span of the roof, characteristics of the appropriate attic structure is determined through computer analysis carried out by specialized engineering services. Cost estimates, design drawings and cutting lists are presented to the local manufacturers. Shop drawings usually show the design loads and stresses in the members, as well as type, size and location of each of the connections.

4.2 Basic Characteristics of the Alternative Attic Structures

The basic characteristics for each of the above mentioned attic structures are presented in Figures (16) to (29). This is the basic information necessary for evaluation of the alternatives. Details of connections and methods of installation including methods of attachment to lower structure are provided by the specialized engineering concerns on the shop drawings. An example is given in Appendix 4. The cost figures given are for an attic span of 8.4 m and a length of 11.9 m. The cost figures given include the cost of structure, installation of structure, sheathing and flooring, insulation and air/vapour barrier. Some of the structural systems identified involve new technologies for which cost estimates are not available at present. However they have been included in the analysis as they will be more widely available in future. More information on cost estimates is given in Appendix 3, and Section 5.

4.3 Selection of Alternative Attic Structures

On the basis of information presented above, some characteristics of the systems can be identified as being critical to the choice of the suitable system(s). Cost per m' of usable floor space, rather than cost figures given in the system charts should be used for evaluation since it incorporates the efficiency in the use of floor space. Other important factors for evaluation are speed of assembly, suitability in terms of environmental conditions and continuity of air/vapour barrier. Of these, cost has

the most influence on the choice of a system, if the other factors are more or less identical. Moreover, some other factors such as ease and speed of construction, amount of materials and labour needed, etc. are reflected in the cost figure. Therefore if the systems are ranked on the basis of the abovementioned factors, more weight should be given to the cost factor. However any ranking exercise can only be meaningful at present and changes in demand, or production of the more newly developed materials, or prefabrication will influence cost, and consequently, the standing of the various alternatives.

Ranking of the alternatives on the basis of the above factors as well as cost are shown below. The cost figures are given as per m^2 of habitable attic area. These figures are based on the cost figures given in the systems charts and table A.3.1. in Appendix 3; and a habitable floor area of 100 m^2 for systems D and E and 72 m^2 for all the other systems.

Attic Systems	Speed of Assembly Non Panel (1) Panel (2)	Environmental Suitability Uncertain (1) Suitable (2)	Provision For Continuity of Air/Vapour Barrier Difficult (1) Simple (2)	Total Rank	Cost/m^2 $ Canadian
A	1	2	1	4	95.8
B	1	2	1	4	97.2
C	1	2	1	4	119.4
D	1	2	2	5	78.0
E	1	2	2	5	85.0
F	1	2	2	5	113.8
G	1	1	2	4	115.27
H	1	2	1	4	118.05
I	1	2	1	4	-
J	1	2	1	4	-
K	2	1	2	5	104
L	2	1	2	5	138.8
M	1	2	2	5	-
N	1	2	2	5	-

Note: The higher rank numbers mean a better situation in each case.

According to these factors systems D and E present the best characteristics with the least cost. Systems A and B are the next best systems in terms of cost. They are also appropriate in terms of environmental suitability. They are the same as all the other non-panel systems in speed of assembly. The provision for continuous air/vapour barrier is more difficult in these two systems than Systems D and E. The other systems are at present very costly and although they may have a better rank than systems A and B, because of their much higher costs they cannot be considered as viable alternatives. Of the four least costly systems, D and E are systems on pony walls and A and B are truss systems with or without an integral floor. Therefore, two systems, i.e. A and D which are the least costly systems in each case have been used for making the cost estimates in the following section.

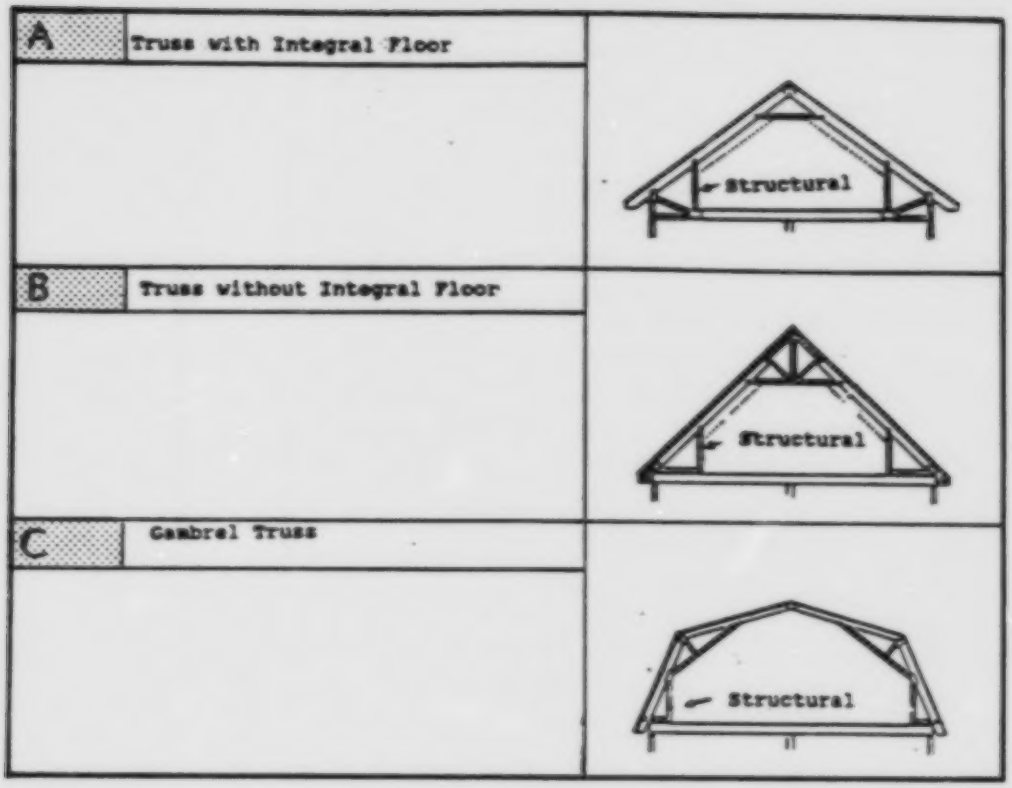


Fig 12 - Attic Structures Using the Truss

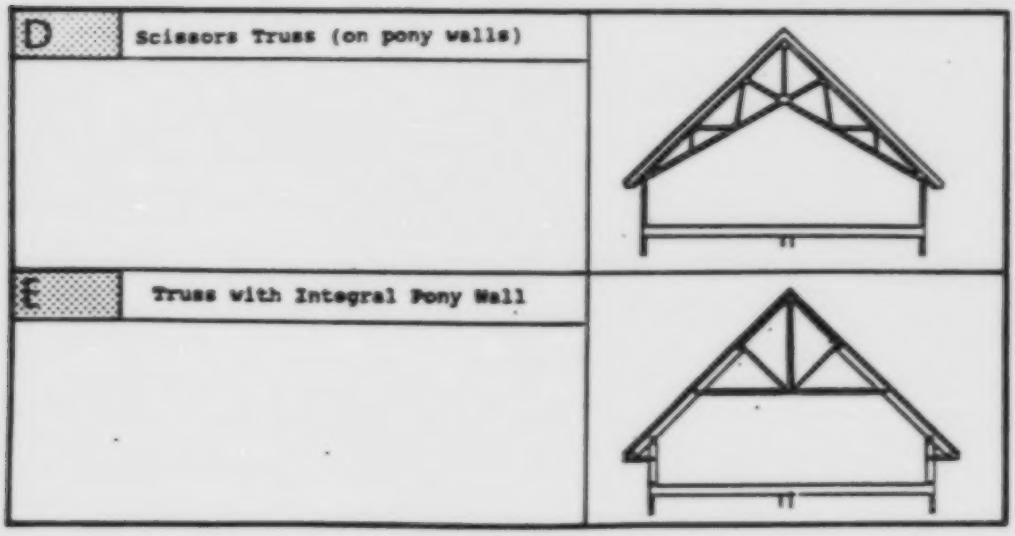


Fig 13 - Attic Structures with Pony Walls

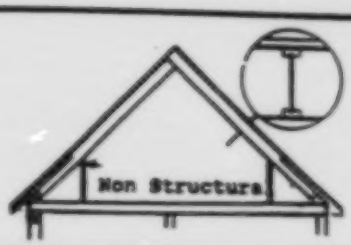
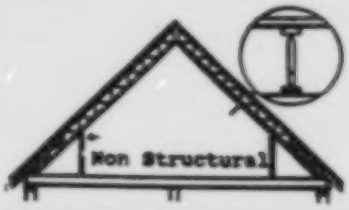
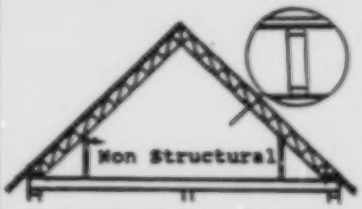
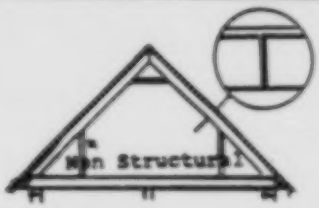
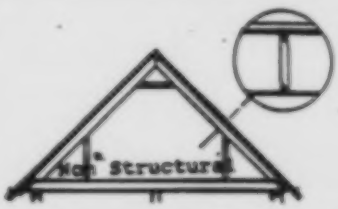
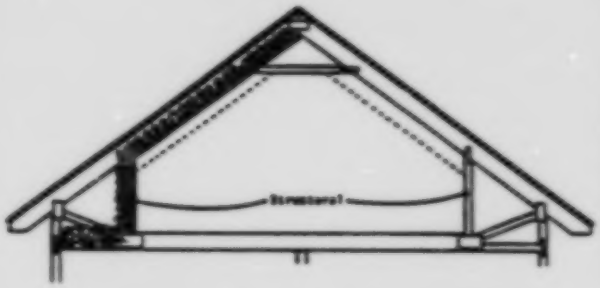
F	Plywood Web Rafters	
C	Steel Pipe Truss Rafters	
H	Flat Laid 2x4 Truss Rafters	
I	Laminated Veneer Lumber	
J	Parallel Strand Lumber	
K	Stressed Skin Plywood Panels	
L	Plywood 'I' Beams With Integral Rigid Insulations	

Fig 14 - Attic Structures Using Rafters or Panels

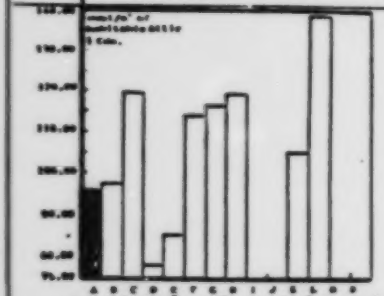
M	Rafters on Purlin Trusses	
N	Attic Truss on Purlin Truss	

Fig 15 - Attic Structures Using the Purlin Truss



A

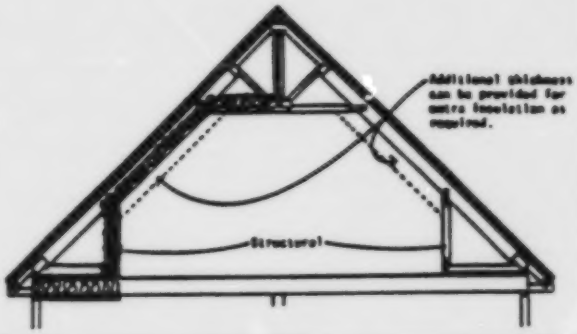
Truss with Integral Floor



cost/m³ of habitable Attic: $ 95.8

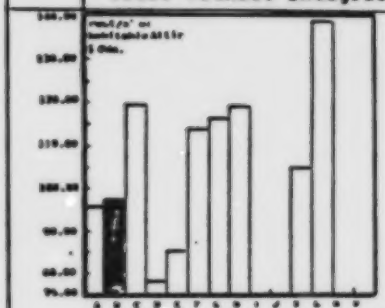
STRUCTURAL SOLUTION:	·	Engineered, factory made truss with integral floor joists.
ENVIRONMENTAL CONTROL:	·	Method of heat-loss, air/vapour and moisture control shown on left of drawing above and Figs. 8, 9,11.
INSTALLATION:	·	Similar to standard trusses, may need crane in larger spans.
SKYLIGHTS AND DORMERS:	·	Easily installed
ADAPTABILITY TO SEMI-DETACHED AND TOWNHOUSES:	·	Possible if truss spans the length of unit.
ADVANTAGES:	·	The system does not need a separate floor joist system.
	·	Simple technology of production and erection.
DISADVANTAGES:	·	Heavy in case of large spans, may need a crane in certain circumstances.
COST: (8.4m span x 11.9 length)	·	$6900.00

Fig 16 .Truss with Integral Floor



B

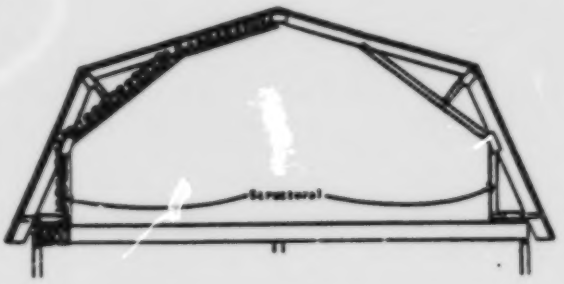
Truss without Integral Floor



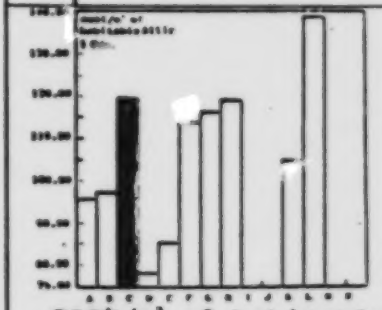
cost/m² of habitable Attic: $ 97.2

STRUCTURAL SOLUTION:	·	Engineered factory made truss without integral floor.
ENVIRONMENTAL CONTROL:	·	Method of heat-loss, air/vapour and moisture control shown on left of drawing above and Figs. 8,9,11.
INSTALLATION:	·	Truss elements and floor joists are manufactured and erected separately but act as one unit once they are connected.
SKYLIGHTS AND DORMERS:	·	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	·	Possible if truss spans length of unit.
ADVANTAGES:	·	The floor system is in place and provides stability and a safe platform for erection of the attic truss.
DISADVANTAGES:	·	
COST: (8.4m span x 11.9m length)	·	$7,000

Fig 17 - Truss without Integral Floor



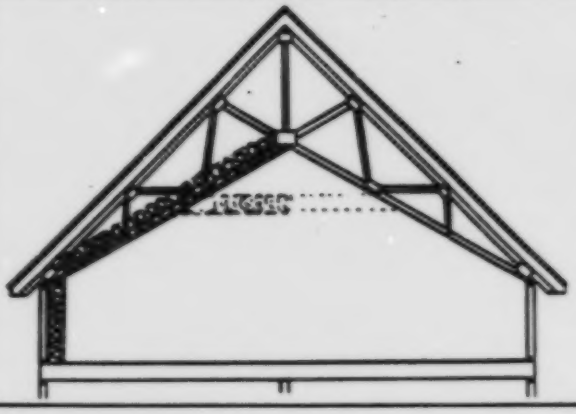
C Gambrel Truss



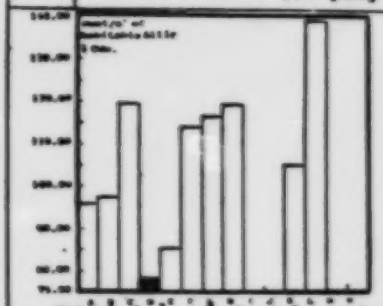
cost/m³ of habitable
Attic: $ 119.4

STRUCTURAL SOLUTION :	.	Engineered factory made truss. Structural behaviour similar to systems B.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control shown on left of drawing above and Figs 8,9,11.
	.	May present ventilation and moisture problems. A collar tie at 2.4 m high could be added to allow adequate ventilation.
INSTALLATION:	.	Systems delivered to site in two pieces. Handling and installation similar to systems B.
SKYLIGHTS AND DORMERS:	.	More complicated to install.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWN HOUSES:	.	Possible if truss spans length of unit.
ADVANTAGES:	.	System provides more width of useable floor area.
DISADVANTAGES:	.	Exterior form of roof and interior spaces not adaptable to many architectural styles.
COST: (8.4m span x 11.9m length)	.	$8600

Fig 18 - Gambrel Truss



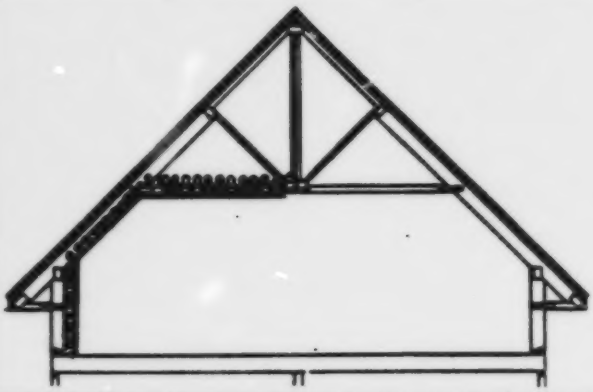
D Scissors Truss (on pony walls)



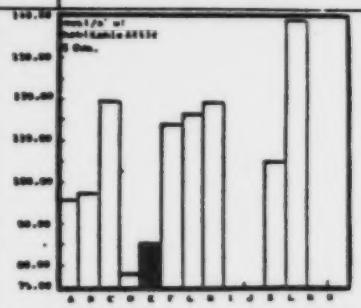
cost/m² of habitable
Attic: $ 78.0

STRUCTURAL SOLUTION :	.	Engineered, factory-made scissors Truss. Structurally, the scissors truss is the same as an ordinary truss with a bottom cord that is not straight.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/ vapour and moisture control shown on left of drawing above and Figs. 8,9,11.
INSTALLATION:	.	A knee or pony wall has to be constructed onto the platform floor prior to truss installation.
SKYLIGHTS AND DORMERS:	.	More complicated
	.	Provisions of window may be possible on pony walls but the low level may not be desirable.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if truss spans the length of unit.
ADVANTAGES:	.	System provides an attic floor the same size as the floor below.
DISADVANTAGES:	.	Fairly large proportion of unusable volume in roof.
COST: (8.4m span x 11.9m length)	.	$ 7800

Fig 19 - Scissors Truss (on Pony Walls)



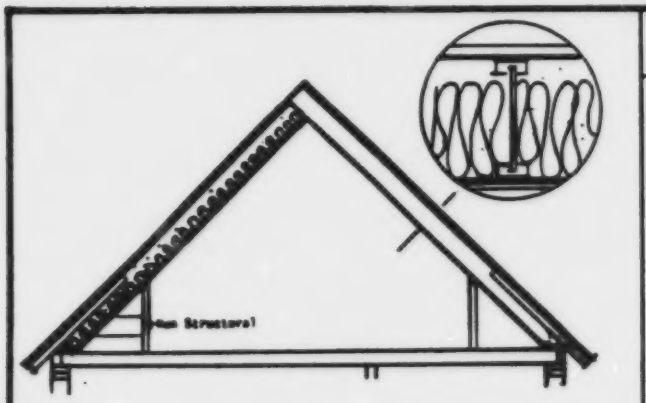
E Truss with Integral Pony Wall



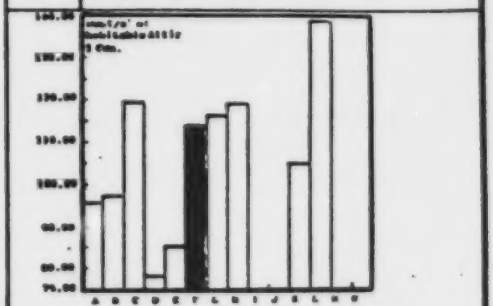
cost/m' of habitable Attic: $ 85.0

STRUCTURAL SOLUTION :	.	Engineered, factory made truss with integral pony walls.
	.	Structurally, system acts as standard house truss, except the tie has been elevated to allow the use of the space below.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control shown on left of drawing above and Figs. 8,9,11.
INSTALLATION:	.	The system delivered to site in two parts, complete with pony walls. Simple installation as the attic floor is already in place, providing a safe working platform.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if truss spans the length of unit.
ADVANTAGES:	.	Provides for full use of the width of building and attic floor area is the same as floor below.
	.	Pony walls are part of the truss and need not be constructed on site.
DISADVANTAGES:	.	May be heavy in case of large spans.
COST: (8.4m span x 11.9 length)	.	$8500

Fig 20 - Truss with Integral Pony Wall



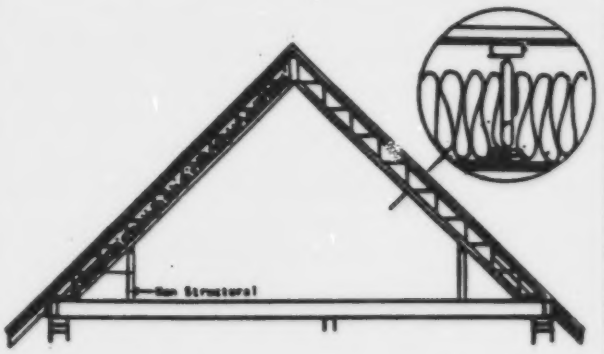
F Plywood Web Rafters



cost/m² of habitable
Attic: $ 113.8

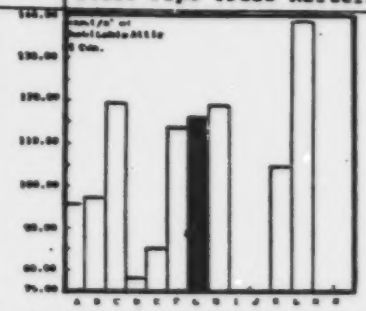
STRUCTURAL SOLUTION:	.	Basically a 3-hinged arch with rafters spanning from eave to ridge. Size and number of rafters determined through computer analysis.
ENVIRONMENTAL CONTROL:	.	Batt or blanket insulation is installed as shown on drawing above, with enough space for ventilation. Air/vapour barriers is installed on warm side. Ventilation is basically as shown in Fig.11.
INSTALLATION:	.	Plywood web rafters designed and cut to size are shipped to site and installed. Sheathing, gypsum board and installation installed on site.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if system spans length of unit.
ADVANTAGES:	. .	Plywood rafters readily accessible. The system is light and easy to handle.
DISADVANTAGES:	.	Plywood webs have to be cut to allow services to pass through them.
COST: (8.4m span x 11.9m length)	.	$8200

Fig 21 - Plywood Web Rafters



G

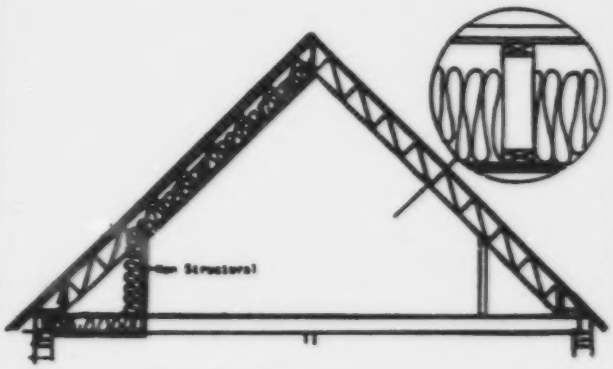
Steel Pipe Truss Rafters



cost/m' of habitable Attic: $ 115.27

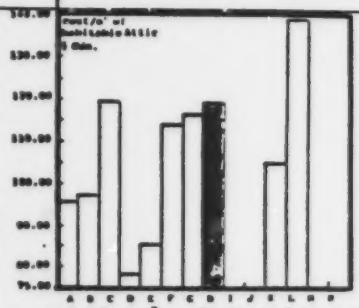
STRUCTURAL SOLUTION :	.	Basically a 3-hinged arch with steel pipe truss rafters spanning from eave to ridge.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control as shown above and in Figs. 8,9,11.
INSTALLATION:	.	Steel pipe truss rafters are shipped to site and installed. Sheathing, insulation, air/vapour barrier and interior gypsum board are installed on site.
	.	Installation details are provided as part of design drawings by the manufacturers.
SKYLIGHTS AND DORMERS:	.	Easy to install in between the truss rafters.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if system spans length of unit.
ADVANTAGES:		easy to install electrical wires and services
DISADVANTAGES:	.	Rafter elements are less readily available.
	.	Condensation is a problem with this system.
COST: (8.4m span x 11.9m length)	.	$8300

Fig 22 - Steel Pipe Truss Rafters



H

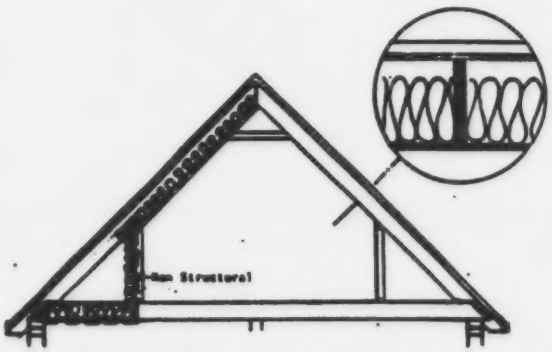
Flat Laid 2x4 Truss Rafters



cost/m³ of habitable Attic: $ 118.05

STRUCTURAL SOLUTION:	.	A 3-hinged arch with flat laid 2x4 truss rafters, spanning from eave to ridge.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control as shown above and in Figs. 8,9,11.
INSTALLATION:	.	The wood truss rafters, manufactured and cut to size are shipped to site and installed.
	.	Exterior sheathing, insulation, air/vapour barrier and gypsum board are installed on site.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	Readily available rafters.
	.	Easy installation and handling on site.
DISADVANTAGES:	.	
COST: (8.4m span x 11.9m length)	.	$8500

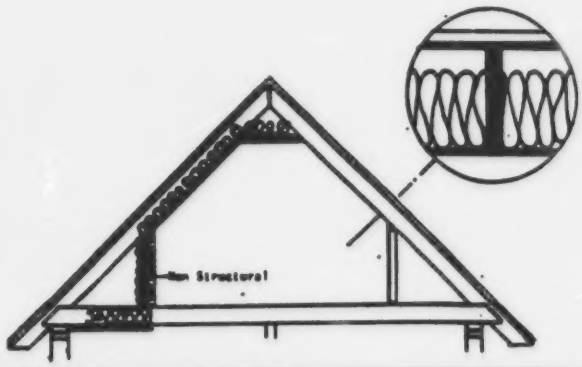
Fig 23. Flat laid 2x4 Truss Rafters



1	Laminated Veneer Lumber

STRUCTURAL SOLUTION :	.	A 3-hinged arch with Laminated Veneer Lumber rafters spanning from eave to ridge.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control, as shown above and in Figs. 8,9,11
INSTALLATION:	.	The rafter elements of LVL are cut to size, shipped to site and installed.
	.	Exterior sheathing, insulation, air/vapour barrier and gypsum board are installed on site.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	Long term advantages as, the LVL process is characterized by use of low value and underutilized species, high process yields and production of high valued products.
DISADVANTAGES:	.	The LVL, being a relatively new product may not be readily available in all areas.
		same labour content as conventional cut framing
COST:	.	Not predictable at present but considered as expensive.

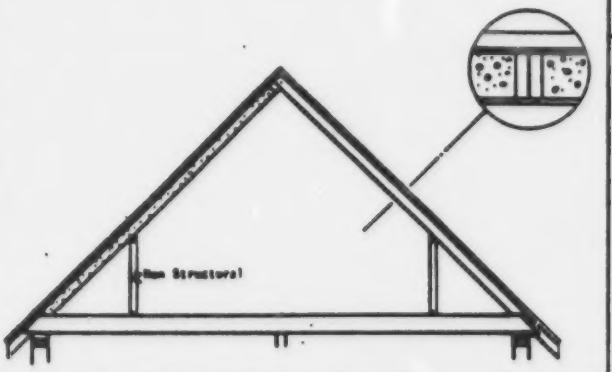
Fig 24 - Laminated Veneer Lumber



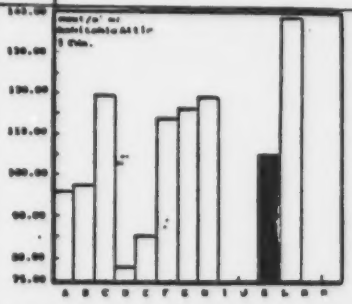
J | Parallel Strand Lumber

STRUCTURAL SOLUTION:	.	A 3-hinged arch with rafters of Parallel Strand Lumber spanning from eave to ridge.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour moisture control as shown above and in Figs. 8,9,11.
INSTALLATION:	.	Rafter elements of PSL are shipped to site and installed. Exterior sheathing, insulation, air/vapour barriers and gypsum board are installed on site.
SKYLIGHTS AND DORMERS:	.	Easily installed
ADAPTABILITY TO SEMI-DETACHED AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	PLS is an engineered timber material which due to its strength, flexibility and uniformity, will be an important alternative to traditional wood products used in residential construction.
DISADVANTAGE:	.	Presently, the availability and cost are not predictable.
COST:	.	Not predictable at present. but considered as high, due to labour content

Fig 25 - Parallel Strand Lumber



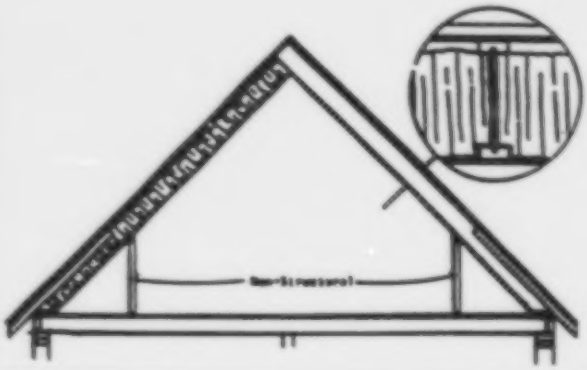
K Stressed Skin Plywood Panels



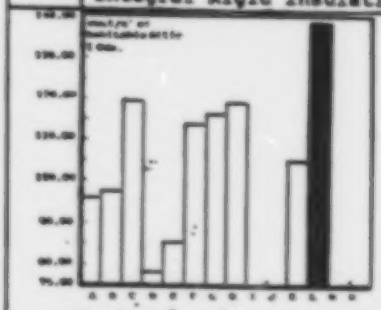
cost/m² of habitable Attic: $ 104.0

STRUCTURAL SOLUTION :	.	The stressed skin panel consist of solid timber webs covered on one or both sides with plywood flanges (skins). The plywood is glued to the solid timber so that the assembly functions as a structural unit. The basic structural behaviour of this system is similar to the last five systems, the only difference being the actual materials used for the "arch" elements.
ENVIRONMENTAL CONTROL:	.	The system has factory installed injected foam insulation and does not provide any means of ventilation. Research is required on durability of the system under extreme weather conditions in Canada.
INSTALLATION:	.	Structure, sheathing, finishes and insulation are combined in one panel and erected at once.
SKYLIGHTS AND DORMERS:	.	Easily installed
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	Reduction in construction time.
DISADVANTAGES:	.	concerns of ventilation.
	.	Panels are heavy and require a crane for handling and installation.
COST: (8.4m span x 11.9m length)	.	$7500

Fig 26 - Stressed Skin Plywood Panels



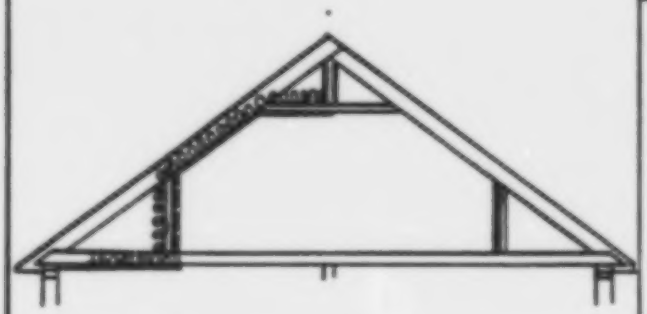
L Plywood 'I' Beams with Integral Rigid Insulations



cost/m' of habitable Attic: $138.8

STRUCTURAL SOLUTION:	.	A 3-hinged arch with rafter elements of plywood 'I' beams and solid infill panels of polystyrene.
ENVIRONMENTAL CONTROL:	.	The panels of plywood beams and rigid insulation are covered with exterior sheathing, and interior installation of a vapour barrier and a drywall. The system does not allow adequate ventilation to avoid moisture problems.
INSTALLATION:	.	The system is shipped to the site as pre-cut panels and installed as a complete system with sheathing, installation and interior finish.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	Reduction in construction time.
DISADVANTAGES:	.	Lack of adequate ventilation.
COST: (8.4m span x 11.9m length)	.	$10,000

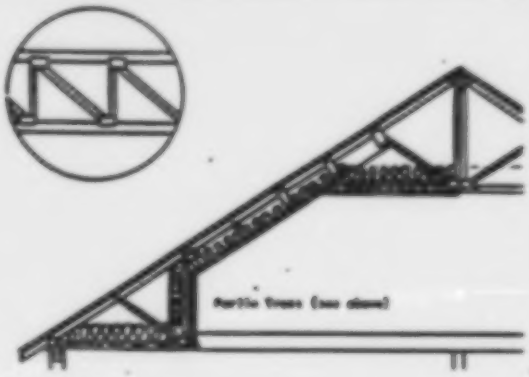
Fig 27 - Plywood 'I' Beams with Integral Rigid Insulation



M | Rafters on Purlin Trusses

STRUCTURAL SOLUTION :	.	Purlin Trusses, running parallel to the ridge are the primary structural elements. The gable or end walls are load bearing.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control, as shown above and in Figs. 8,9,11.
INSTALLATION:	.	The system is shipped to site as three purlin trusses and wood rafters cut to size, the roof is assembled on site and exterior sheathing, insulation, air/vapour barrier and drywall are installed.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Possible if roof spans length of unit.
ADVANTAGES:	.	The system is light and easy to install, does not need any cranes.
DISADVANTAGES:	.	-----
COST:	.	Not available at this time due to uniqueness of application

Fig 28- Rafters on Purlin Trusses



N	Attic Truss on Purlin Truss

STRUCTURAL SOLUTION :	.	This combination of trusses is a structural solution for a narrow frontage row-house where the bearing is on the parting walls. This system combines several interesting structural ideas. First, its an exception to the norm of systems spanning "wall-to-wall" as the spans are significantly reduced by the provisions of purlin trusses spanning the other way. There must, of course, be the opportunity of providing reactions for these purlin trusses somewhere in the planning of the spaces. The size of these trusses will depend on the length of the purlin truss spans as well as the width of the house itself. In the centre space the system is similar to System E. On the wings are a pair of triangle trusses common to typical residential construction.
ENVIRONMENTAL CONTROL:	.	Method of heat-loss, air/vapour and moisture control, as shown above and in Figs. 8,9,11.
INSULATION:	.	The system is shipped in six pieces, assembled on site and exterior sheathing, insulation, air/vapour barrier and drywall as installed.
SKYLIGHTS AND DORMERS:	.	Easily installed.
ADAPTABILITY TO SEMI-DETACHED UNITS AND TOWNHOUSES:	.	Easily adaptable.
ADVANTAGES:	.	Adaptability.
DISADVANTAGES:	.	------
COST:		Not available at this time due to uniqueness of application

Fig 29-Attic Truss on Purlin Truss

5. COST ANALYSIS

The main purpose of the present study has been to show that it is economically efficient to use the attic space for habitation. Many structural solutions for providing a habitable attic space have been presented. But the public acceptance of the attic as a viable alternative to an upper storey, or as a future potential area for expansion, depends on the economic efficiency of these solutions. A cost comparison between identical units with and without a habitable attic has been carried out to evaluate the efficiency of the habitable attic.

5.1 Type of Attic Structures Used in the Cost Comparisons

As discussed earlier, of the systems without the pony wall, System A, the truss with the integral floor, is the least costly. System D, which is a scissor truss on pony wall has the lowest cost per m' of usable floor space provided and is therefore the most cost efficient system. The cost comparisons presented are on the basis of the use of these two systems.

5.2 Definition of Units for Comparison

Ten different types of units have been defined in Figures (30) to (39). The basements have not been shown in the drawings and only stairs or locations of stairs are shown. These units are as follows:

- one storey house (bungalow)
  area 100 m'

- one storey house - area 100 m'
  extension - area 72 m'
  total area - 172 m'

- one storey house with potential attic - main floor area 100 m²
  potential attic (not on pony wall) - area 72 m², total 172 m²
  potential attic (on pony wall) - area 100 m² , total 200 m²

- one storey house with finished attic - main floor area 100 m²
  finished attic (not on pony wall) - area 72 m², total 172 m²
  finished attic (on pony wall) - area 100 m² - total 200 m²

- one storey house with potential attic - main floor area 60 m²
  potential attic (not on pony wall) - area 40 m² - total 100 m²
  potential attic (on pony wall) - area 60 m² - total 120 m²

- one storey house with finished attic - main floor area 60 m²
  finished attic (not on pony wall) - area 40 m² - total 100 m²
  finished attic (on pony wall) - area 60 m² - total 120 m²

- two storey house - area 121 m²

- two storey house with potential attic-area without attic 121 m²
  potential attic (not on pony wall) - area 44 m² - total 165 m²
  potential attic (on pony wall) - area 60.5 m² - total 181.5 m²

- two storey house with finished attic - area without attic 121 m²
  finished attic (not on pony wall) - area 44 m² - total 165 m²
  finished attic (on pony wall) - area 60.5 M² - total 181.5 m²

- one storey house with finished attic (not on pony wall)area 121 m²
  one storey house with finished attic (on pony wall) -area 141 m²

5.3. Factors Considered for the Cost Analysis

The units presented in figures (30) to (39) have been used as the basis for the cost comparison. Six different comparisons have been carried out and the results are shown in figures (40) to (45). The comparisons have been made between the following units.

a. A finished bungalow (100 m' area) compared with a 1 1/2 storey house with a finished ground floor area of 100 m' and a potential, unfinished attic of 72 m' (attic type A) and 100 m', (attic type D)

b. A finished bungalow (100 m' area) plus a finished on-grade extension of 72 m' (total area 172 m'), compared with a finished 1 1/2 storey house of same area 172 m' (attic A) and one of 200 m' (attic D)

c. A bungalow and a 1 1/2 storey house of same area 100 m' (attic A) and one of 120 m' (attic D)

d. A 2 storey house and a 1 1/2 storey house of same area 121 m' (attic A) and one of 141 m' (attic D)

e. A 2 storey house (121 m')and the same unit but with a potential attic total area 165 m' (attic A) and one of 181.5 m' (attic D)

f. A one storey house with unfinished attic compared to one with finished attic for type A truss, total area 100 m2, and type D truss total area 120 m'

Details of the cost comparisons are shown in Appendix 3.

The following elements have been taken into account in the comparison of construction costs:

- Basement excavation
- Foundations
- Basement walls
- Slab on grade
- Upper floor construction
- Attic construction
- Roof construction and insulation
- Roof finish
- Exterior walls, insulation and exterior finish
- Interior walls
- Stairs
- Drywall to walls and ceilings.

- Interior doors
- Interior finishes
- Fittings and equipment
- Electrical
- Heating
- Plumbing

The following elements have not been accounted for in these comparisons:

- Site preparation
- Exterior doors and windows
- kitchen appliances

As mentioned earlier the details of these costs are shown in Appendix (3).

5.4 Results of Cost Comparisons

Cost comparison (a), Figure 40, is between the cost of a finished bungalow, a 1 1/2 storey house with finished ground floor area of the same size with a potential attic, and the same 1 1/2 storey house with finished attic. Two attic systems, A and D, have been used. The comparison shows that:

- For an additional 15 to 22 percent increase in cost, the potential for a future expansion of between 72 to 100 percent will be provided for.

- To finish the attic space, the initial cost of the bungalow will have to be increased by a further 23 to 30 percent. So in total for an addition of 28 to 52 percent on the initial cost, the total habitable area will be increased by 72 to 100 percent.

- The cost per m² of the finished floor area for the bungalow is $524.26, as compared with $420.28/m² for the 1 1/2 storey house with attic type A and $402.37/m² for the house with attic type D. So the cost per m² of the units with the attic is between 20 to 23% lower than the bungalow with the regular truss.

Comparison (b), Figure 41, is between a one storey bungalow of 100 m² with an on grade addition of 72 m², and a bungalow with the same ground floor area but with a finished attic area of 72 m² or 100 m². The purpose of the comparison is to see whether it would be less costly to expand in an attic area rather than on grade. The cost figures presented in comparisons (a) and (b) show that:

- For an on-grade extension of 72 m², an additional cost of $29,911 would be necessary over the $52,426 cost of the bungalow. To provide the same accomodation in the attic the cost would be $19,863.

- In terms of cost/m² of habitable area, the cost for the bungalow with the on-grade extension is $ 478.70/m², and $420.28/m² and $402.37/m² for the houses with attic types A and D respectively.

- Therefore, the cost of providing the needed expansion is lower if the expansion is in an attic rather than an on-grade addition. The other advantage is the possibility of breaking down the costs into an initial $ 7,839 to provide for a potential attic and a $ 12,024 expenditure to finish the attic at a later stage (for attic type A). In short it is cheaper to finish a potential attic than to build an addition.

Comparison (c), Figure 42, shows the cost of providing 100 m² in a bungalow as compared with providing the same area in a 1 1/2 storey house (attic system A), or 121 m² in a 1 1/2 storey house (attic D). The comparison shows that:

- It costs less to build a 1 1/2 storey house using an attic truss than to build a bungalow with a regular lightweight truss. In other words it is economically more efficient to use the area under the roof for habitation by using an attic truss, rather than a standard truss.

- Comparison of cost/m² figures presented in (a) and (c) show that the cost/m² of habitable area is less in the larger units presented in Fig. 40, for the units with the attic systems.

Comparison (d) Fig. 43, is between the cost of a 2 storey house of 121 m² area and a 1 1/2 storey house of same area (attic A) and a 1 1/2 storey house of 141 m² (attic D). It shows that:

- When we use the attic type A the cost/m² of the 2 storey house is significantly lower than the 1 1/2 storey house which contradicts the results of the previous comparisons. However the main reason for this is the exclusion of the basement area in the house area calculations. The one storey house with the finished attic type A, has a basement area of 71 m² while the 2 storey house has a basement area of 60 m². The costs can thus be calculated as follows:

Description	Area	Estimated Cost	Cost per m²
two storey house (excluding basement floor area)	121m²	$56,062	$463.32
one storey house with finished attic (type A) (excluding basement floor area)	121m²	$57,470	$474.96
two storey house (including basement floor area)	181m²	$56,062	$309.73
one storey house with finished attic (type A) (including basement floor area)	192m²	$57,470	$299.32

These results are in support of the previous arguments.

- The figure given for the 1 1/2 storey house with attic type (D), show that the costs/m² is less for the 1 1/2 storey house as compared to the 2 storey house.

The purpose of comparison (e), Fig. 44, is to see if it is economically more efficient to use an attic truss rather than a regular truss on a 2 storey house. It shows that:

- If the initial cost of construction is increased by $5,414 to $8,132 (9.6 to 14.5 percent), the potential for a future expansion of between 44 m² to 60.5 m² will be provided for.

- The cost/m² of the finished two storey house with attics A and D is $416.72, and $408.57 respectively, as compared to the $463.32/m² for the 2 storey house with the regular truss. In other words, it is economically more efficient to use an attic truss instead of a regular lightweight truss for a 2 storey house since the cost per m² of habitable area provided will be reduced by 10 to 12 percent by using the attic truss A and D rather than the regular truss.

In comparison (f), Fig. 45, the cost of the 1 1/2 storey house with unfinished attic is compared to the cost of the 1 1/2 storey house with finished attic. The cost figures presented in Figs. 40 and 45 show that:

- It is about $10,000 less costly to buy a 1 1/2 storey house with unfinished attic than to buy a fully finished bungalow of 100 m². This comparison supports the argument already put foreward on the advantages of attic houses for first time buyers. With an expenditure of about $42,000 a family can buy a 60 m² house with the potential for expansion of 40 m² or 60 m² in the attic at a later date.

- The expenses for finishing the attic in future is estimated between $7,772 and $9,544 for attic types A and D respectively. Therefore, in the case of a first time buyer, the finishing expenses can occur with the increase in space needs and growth of income.

- Apart from the possibility of a two phase expenditure, the total cost of the 1 1/2 storey house is also less than the cost of the bungalow, further supporting the already established economic efficiency of the attic truss.

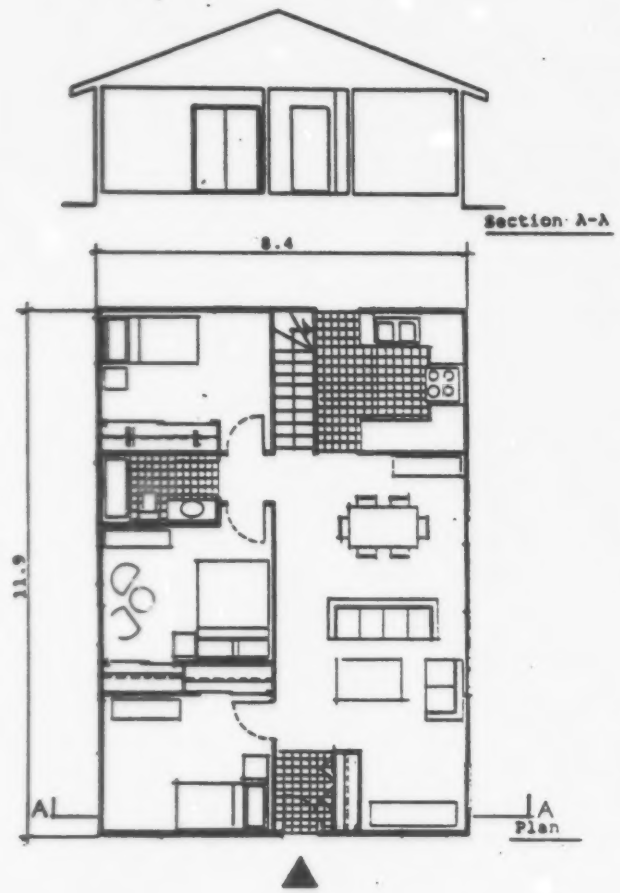


FIG 30 - ONE STOREY HOUSE (BUNGALOW)
AREA 100 M²

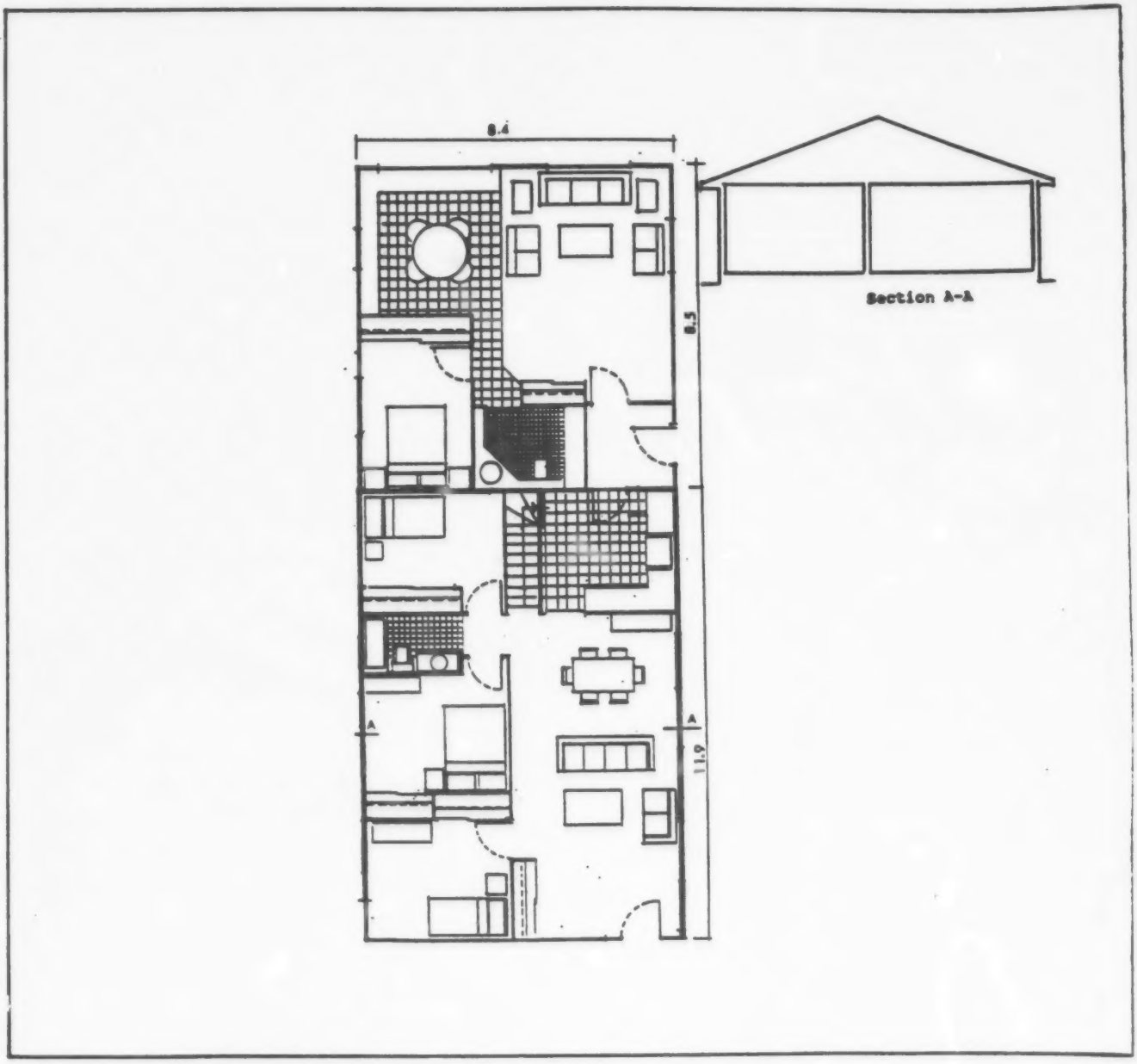


FIG 31 - ONE STOREY HOUSE - AREA 100 M²
EXTENSION - AREA 72 M²
TOTAL AREA - 172 M²

FIG 32 - ONE STOREY HOUSE WITH POTENTIAL ATTIC - MAIN FLOOR AREA 100 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 72 M², TOTAL 172 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 100 M² , TOTAL 200 M²

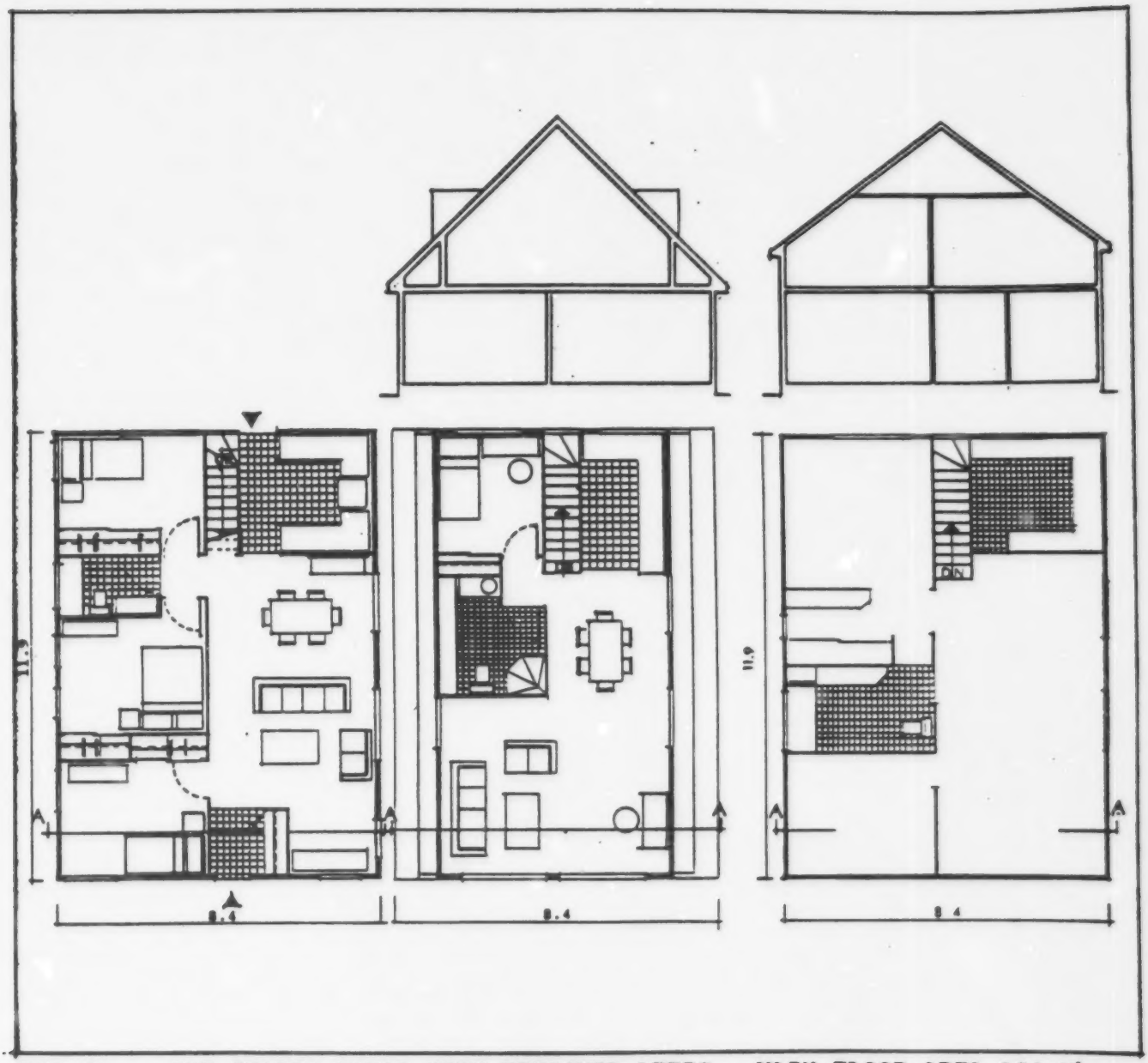


FIG 33 - ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 100 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 72 M², TOTAL 172 M²
FINISHED ATTIC (ON PONY WALL) - AREA 100 M² - TOTAL 200 M²

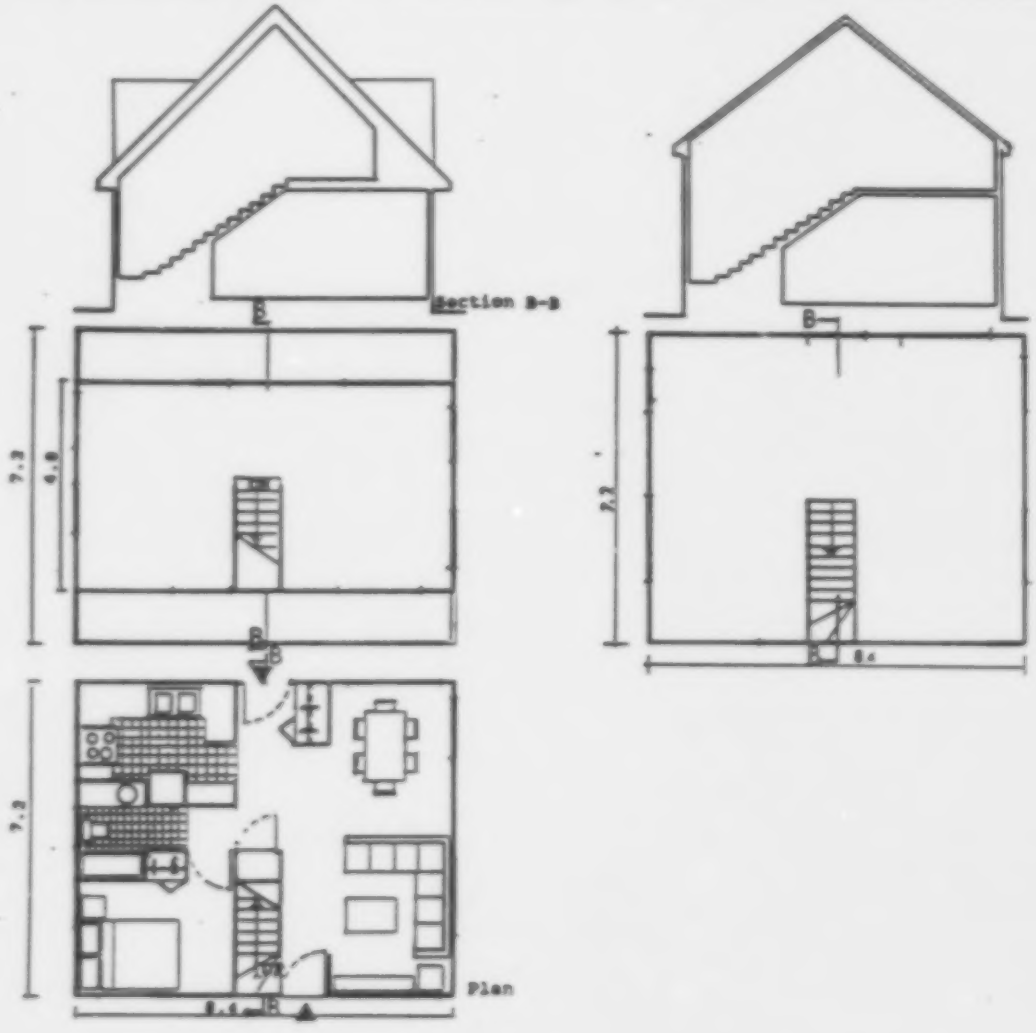


FIG 34 - ONE STOREY HOUSE WITH POTENTIAL ATTIC - MAIN FLOOR AREA 60 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 40 M² - TOTAL 100 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 60 M² - TOTAL 120 M²

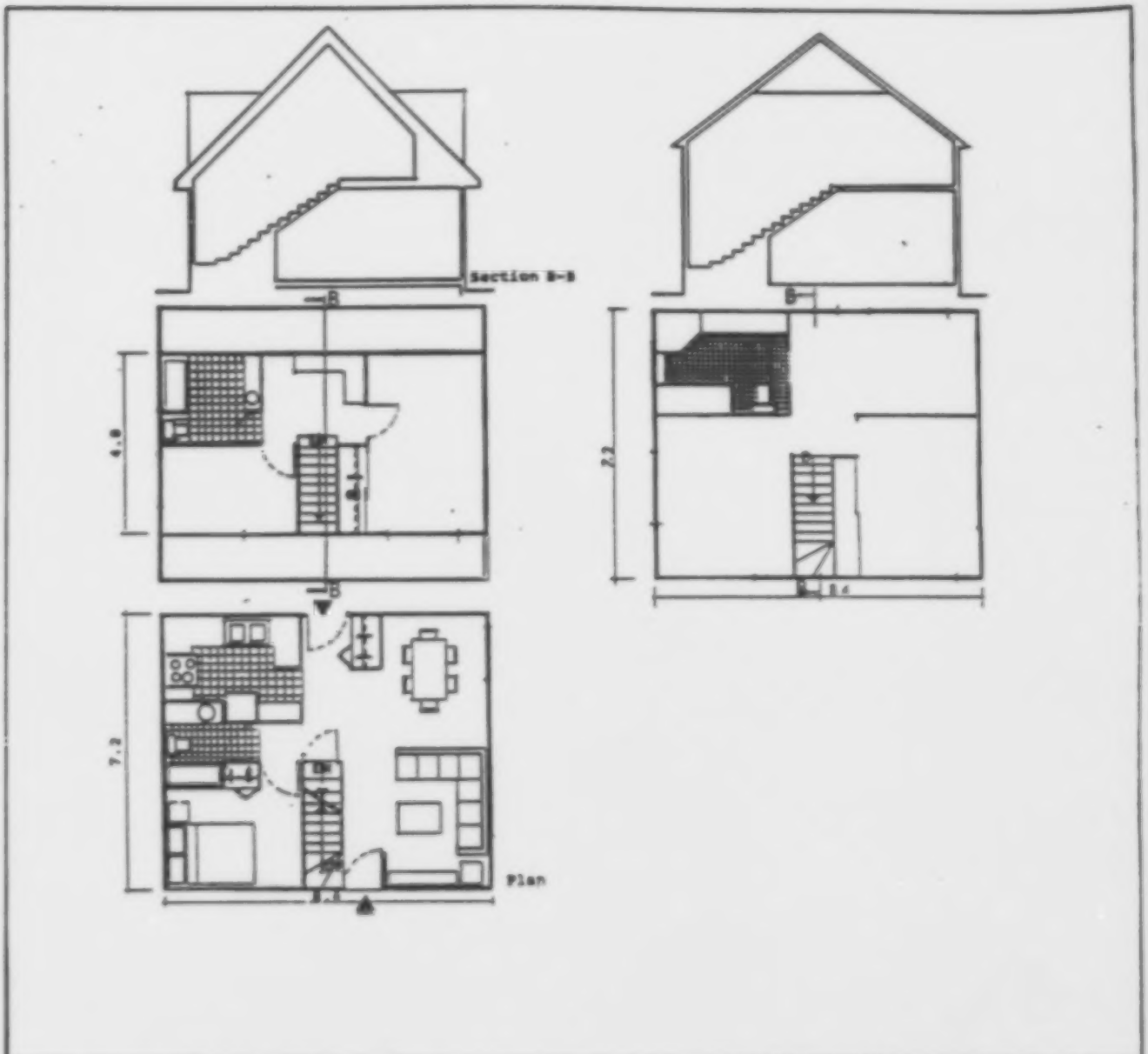


FIG 35 - ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 60 M'
FINISHED ATTIC (NOT ON PONY WALL) - AREA 40 M' - TOTAL 100 M'
FINISHED ATTIC (ON PONY WALL) - AREA 60 M' - TOTAL 120 M'

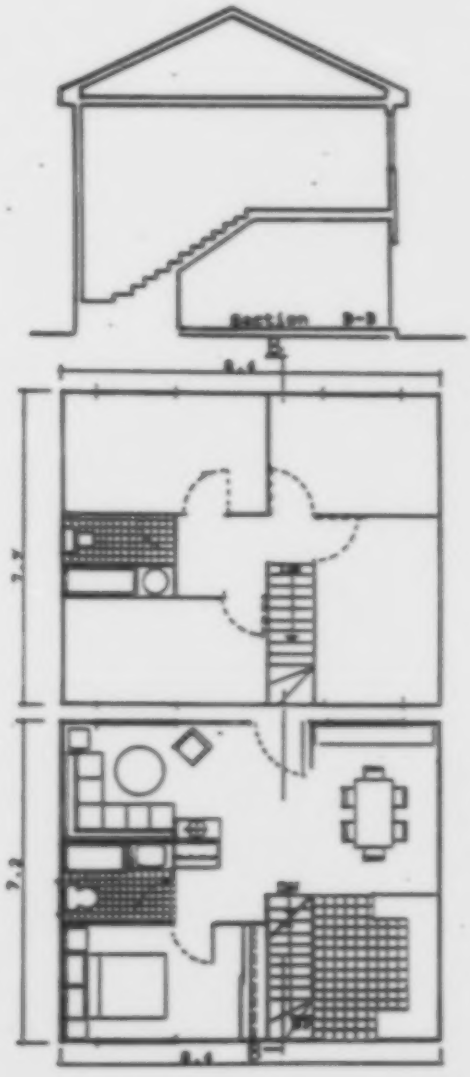


FIG 36 - TWO STOREY HOUSE - AREA 121 M²

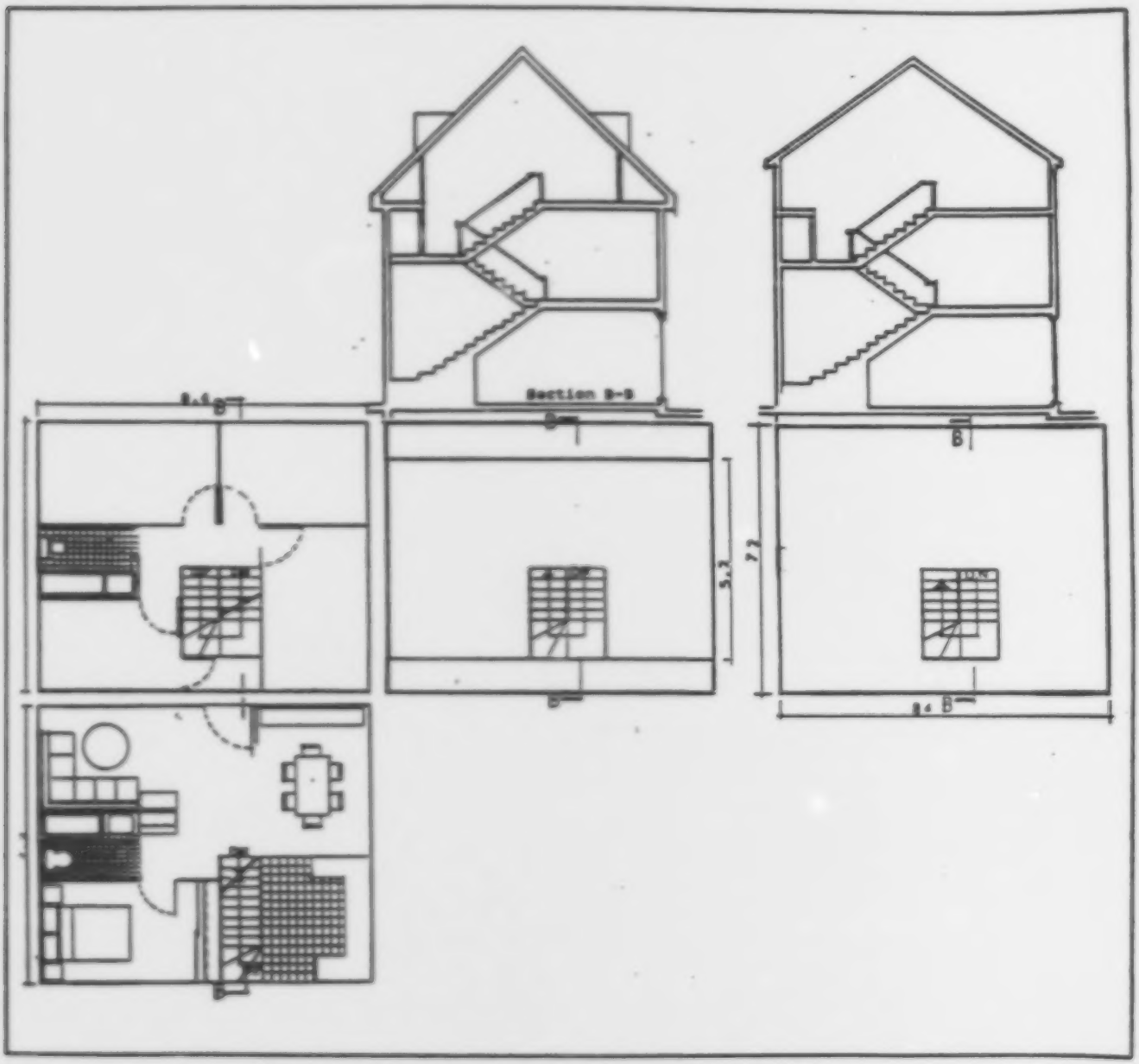


FIG 37 - TWO STOREY HOUSE WITH POTENTIAL ATTIC-AREA WITHOUT ATTIC 121 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 44 M² - TOTAL 165 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 60.5 M² - TOTAL 181.5 M²

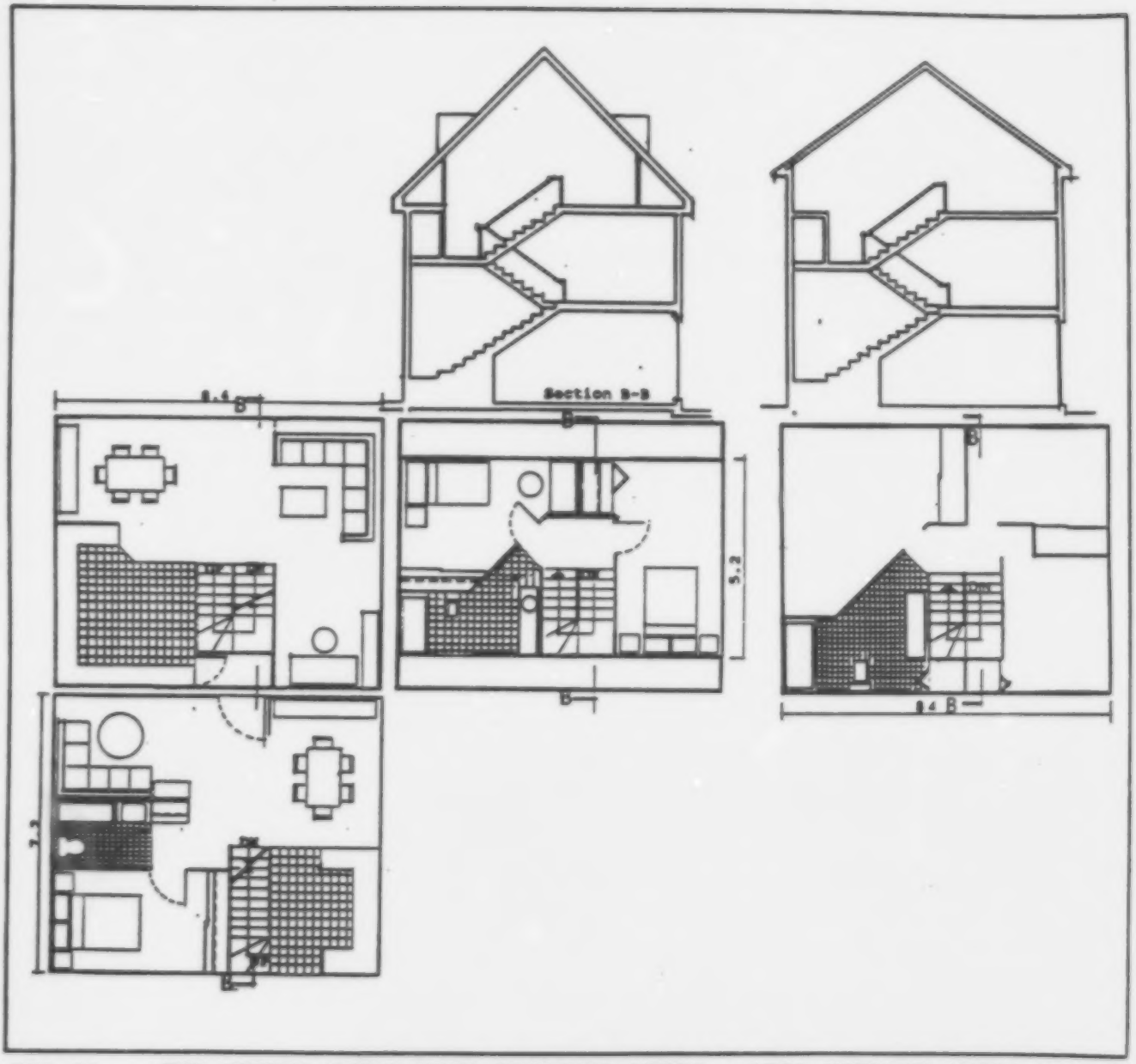


FIG 38 TWO STOREY HOUSE WITH FINISHED ATTIC - AREA WITHOUT ATTIC-121 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 44 M² - TOTAL 165 M²
FINISHED ATTIC (ON PONY WALL) - AREA 60.5 M² - TOTAL 181.5 M²

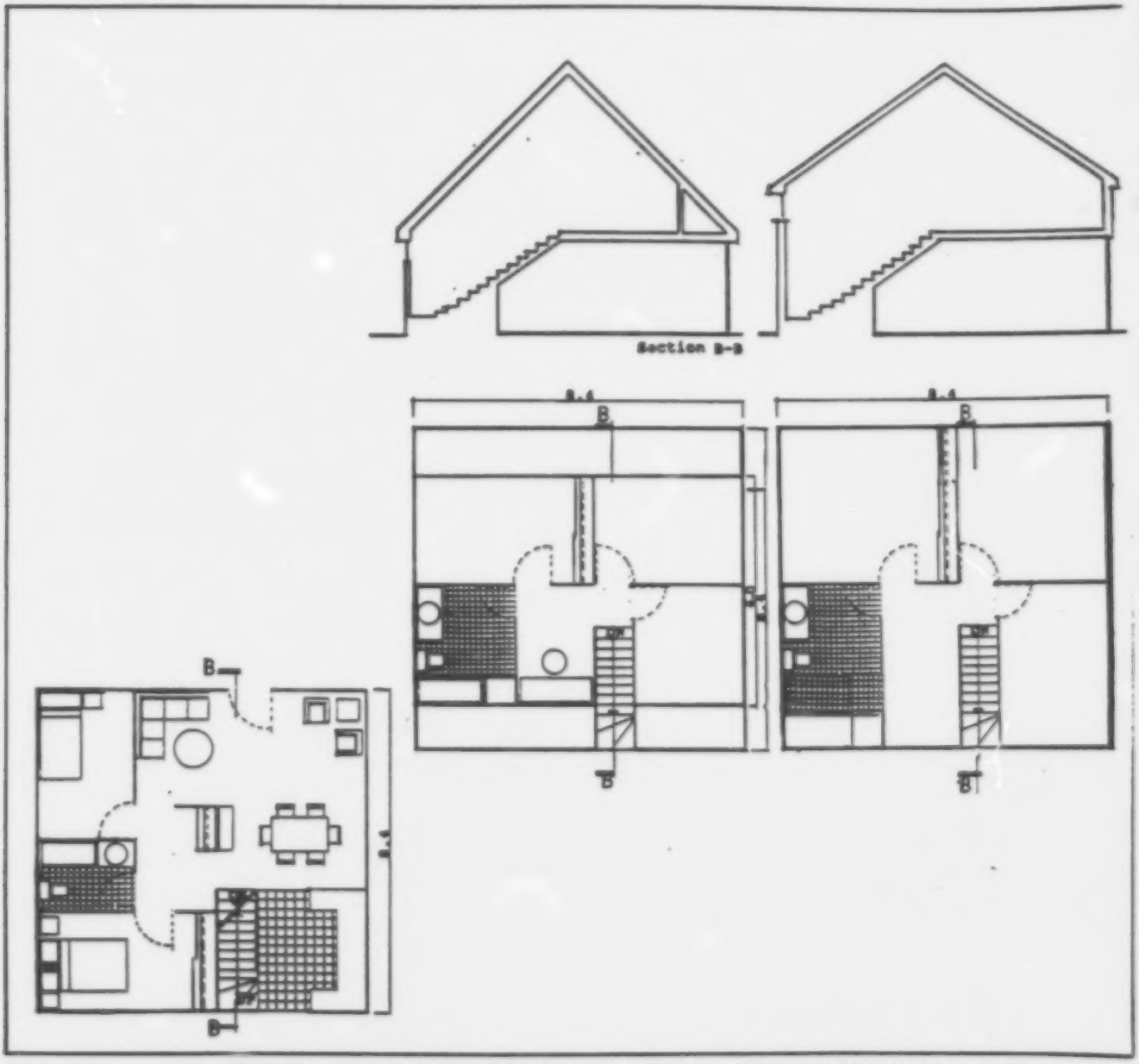
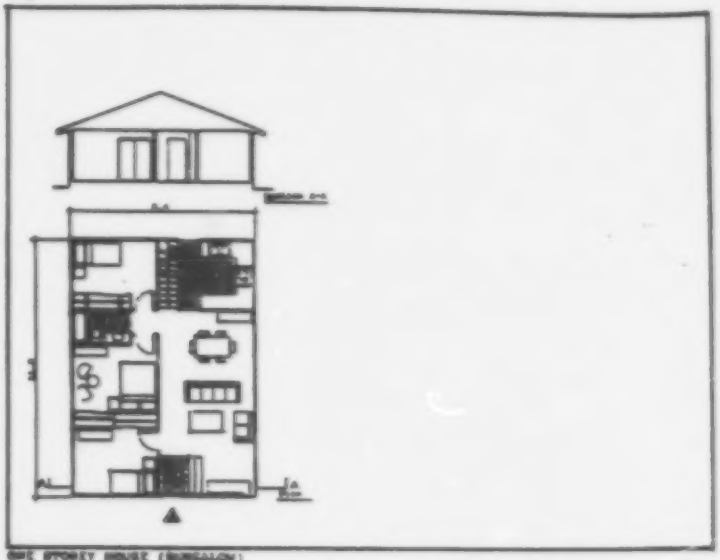


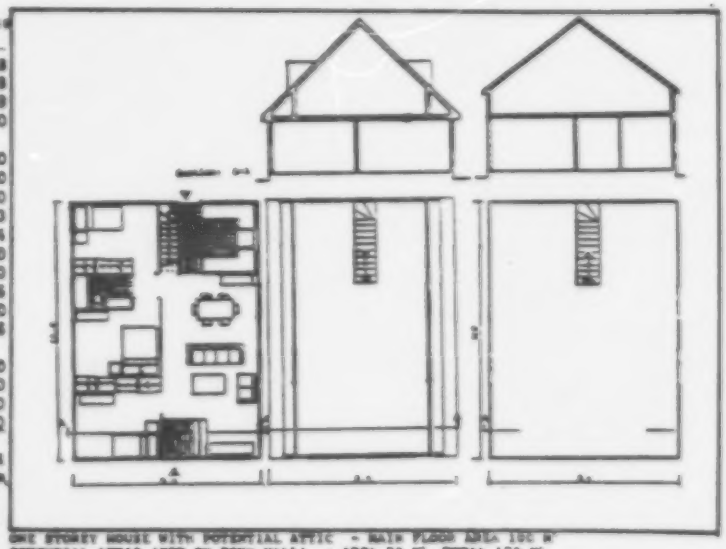
FIG 39 ONE STOREY HOUSE WITH FINISHED ATTIC (NOT ON PONY WALL)AREA 121 ft
ONE STOREY HOUSE WITH FINISHED ATTIC (ON PONY WALL) - AREA 141 ft

Element	One Storey House Area 180m²
1. Basement excavation	2,988
2. Foundations	2,288
3. Basement walls	10,439
4. Slab on grade	2,100
5. Upper floor construction	3,300
6. Attic construction	-
7. Roof construction	3,400
8. Roof finish	1,602
9. Exterior walls	4,140
10. Interior walls	885
11. Stairs	780
12. Drywall	4,668
13. Interior doors	840
14. Interior finishes	4,046
15. Fittings and equipment	2,570
16. Electrical	3,000
17. Heating	3,200
18. Plumbing	2,400
Total Amounts	$ 52,475
Cost per m²	324.26
Cost per sf	48.70



ONE STOREY HOUSE (BUNGALOW)
AREA 180 M²

Element	with Unfinished Attic Type A Truss Area 172 m²	with Unfinished Attic Type B Truss Area 200 m²
1. Basement excavation	2,988	2,988
2. Foundations	2,288	2,288
3. Basement walls	10,439	10,439
4. Slab on grade	2,100	2,100
5. Upper floor construction	3,300	3,300
6. Attic construction	864	2,610
7. Roof construction	6,900	7,800
8. Roof finish	1,704	1,533
9. Exterior walls	5,040	5,904
10. Interior walls	770	770
11. Stairs	1,560	1,560
12. Drywall	5,256	6,636
13. Interior doors	840	840
14. Interior finishes	4,046	4,046
15. Fittings and equipment	2,570	2,570
16. Electrical	3,000	3,000
17. Heating	3,200	3,200
18. Plumbing	2,400	2,400
Total Amounts	$ 60,265	$ 63,984
Cost per m²	350.38	319.92
Cost per sf	32.55	29.72



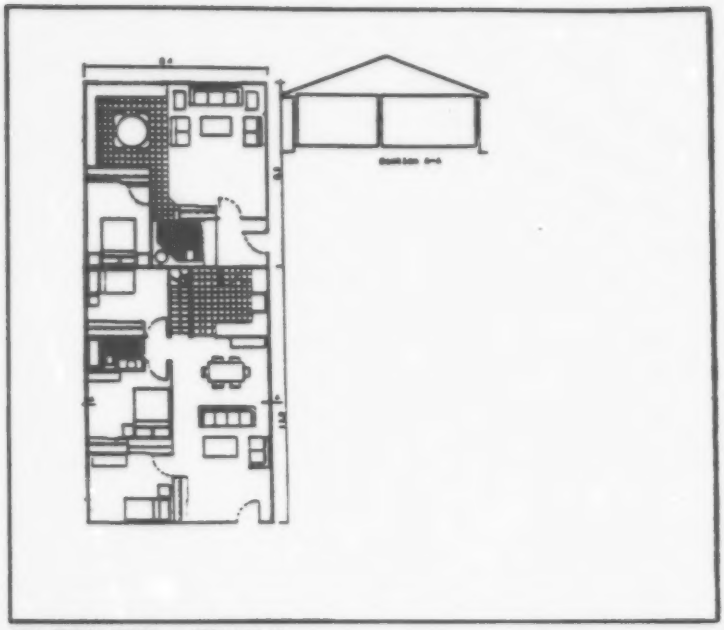
ONE STOREY HOUSE WITH POTENTIAL ATTIC - MAIN FLOOR AREA 180 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 72 M², TOTAL 172 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 100 M² , TOTAL 200 M²

Element	with Finished Attic Type A Truss Area 172 m²	with Finished Attic Type B Truss Area 200 m²
1. Basement excavation	2,988	2,988
2. Foundations	2,288	2,288
3. Basement walls	10,439	10,439
4. Slab on grade	2,100	2,100
5. Upper floor construction	3,300	3,300
6. Attic construction	864	2,610
7. Roof construction	6,900	7,800
8. Roof finish	1,704	1,533
9. Exterior walls	5,040	5,904
10. Interior walls	945	1,057
11. Stairs	1,560	1,560
12. Drywall	7,677	8,494
13. Interior doors	1,260	1,680
14. Interior finishes	7,084	7,084
15. Fittings and equipment	4,380	5,226
16. Electrical	5,160	6,000
17. Heating	4,300	5,000
18. Plumbing	4,400	4,400
Total Amounts	$ 72,289	$ 80,474
Cost per m²	420.28	402.37
Cost per sf	39.05	37.38

ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 180 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 72 M², TOTAL 172 M²
FINISHED ATTIC (ON PONY WALL) - AREA 100 M² - TOTAL 200 M²

Fig 40 - Comparison (a)

Element	One Storey House (Bungalow) with an Extension, Area 172m²
1. Basement excavation	4,869
2. Foundations	3,057
3. Basement walls	14,832
4. Slab on grade	3,612
5. Upper floor construction	5,676
6. Attic construction	-
7. Roof construction	6,848
8. Roof finish	2,751
9. Exterior walls	5,616
10. Interior walls	1,008
11. Stairs	780
12. Drywall	6,738
13. Interior doors	1,680
14. Interior finishes	6,690
15. Fittings and equipment	4,920
16. Electrical	5,160
17. Heating	4,300
18. Plumbing	4,800
Total Amounts	$ 82,337
Cost per m²	478.70
Cost per sf	44.47



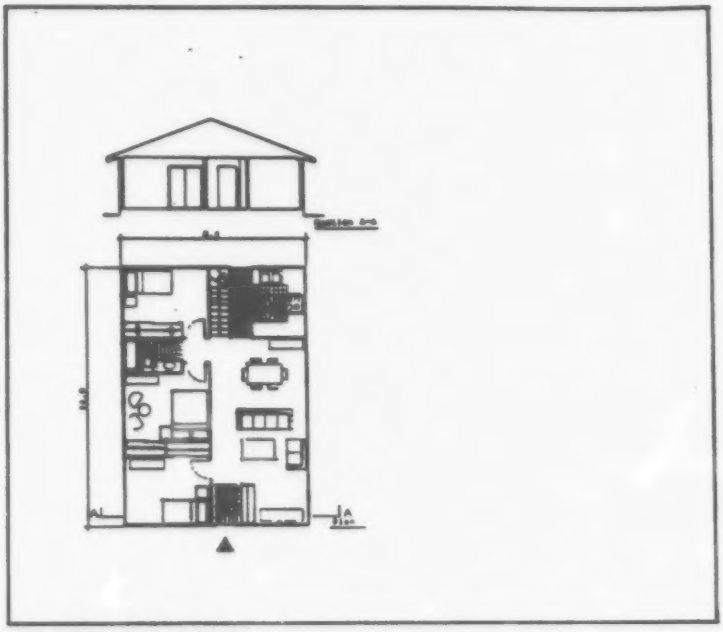
ONE STOREY HOUSE - AREA 100 M²
EXTENSION - AREA 72 M²
TOTAL AREA - 172 M²

Element	with Finished Attic Type A Truss Area 172 m²	with Finished Attic Type B Truss Area 300 m²
1. Basement excavation	2,988	2,988
2. Foundations	2,288	2,288
3. Basement walls	10,439	10,439
4. Slab on grade	2,100	2,100
5. Upper floor construction	3,300	3,300
6. Attic construction	864	2,610
7. Roof construction	6,800	7,800
8. Roof finish	1,704	1,533
9. Exterior walls	5,040	5,804
10. Interior walls	945	1,057
11. Stairs	1,560	1,560
12. Drywall	7,577	8,494
13. Interior doors	1,260	1,680
14. Interior finishes	7,084	7,995
15. Fittings and equipment	4,380	5,326
16. Electrical	5,160	6,000
17. Heating	4,300	5,000
18. Plumbing	4,400	4,400
Total Amounts	$ 72,389	$ 80,474
Cost per m²	420.28	402.37
Cost per sf	39.05	37.38

ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 100 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 72 M², TOTAL 172 M²
FINISHED ATTIC (ON PONY WALL) - AREA 100 M² - TOTAL 300 M²

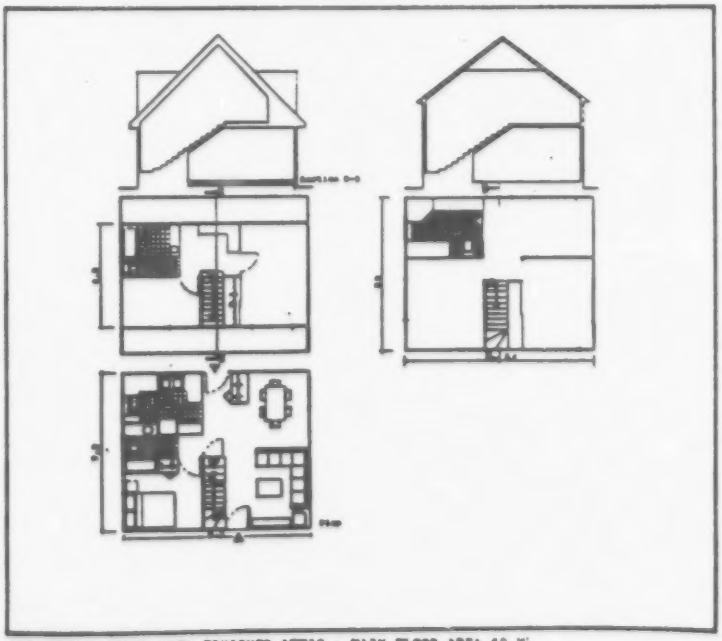
Fig 41 - Comparison (b)

Element	One Storey House (Bungalow) Area 100m²
1. Basement excavation	2,888
2. Foundations	2,288
3. Basement walls	10,439
4. Slab on grade	2,100
5. Upper floor construction	3,300
6. Attic construction	-
7. Roof construction	3,400
8. Roof finish	1,602
9. Exterior walls	4,140
10. Interior walls	665
11. Stairs	780
12. Drywall	4,668
13. Interior doors	840
14. Interior finishes	4,046
15. Fittings and equipment	2,570
16. Electrical	3,000
17. Heating	3,200
18. Plumbing	2,400
Total Amounts	$ 62,426
Cost per m²	624.26
Cost per sf	48.70



ONE STOREY HOUSE (BUNGALOW)
AREA 100 M²

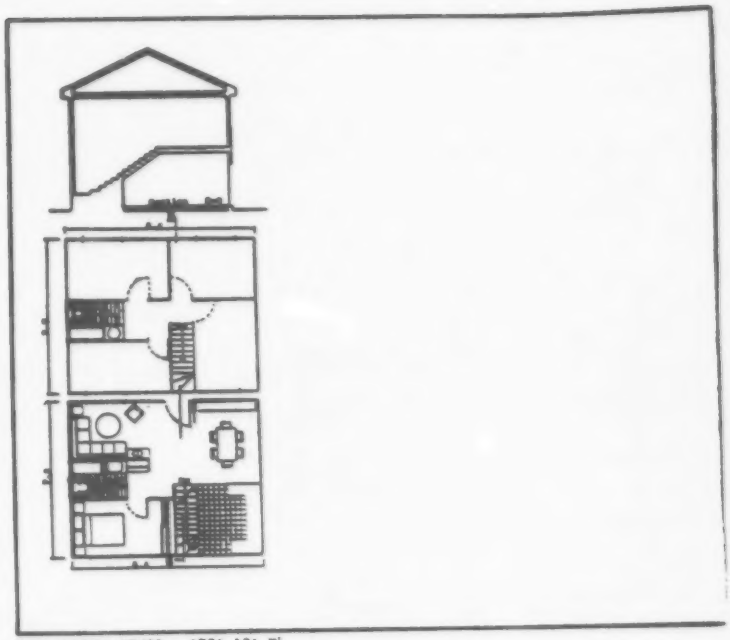
Element	One Storey House with Finished Attic Type A Truss Area 100 m²	One Storey House with Finished Attic Type D Truss Area 120 m²
1. Basement excavation	1,953	1,953
2. Foundations	1,729	1,729
3. Basement walls	7,965	7,965
4. Slab on grade	1,260	1,260
5. Upper floor construction	1,980	1,980
6. Attic construction	465	1,044
7. Roof construction	4,140	5,120
8. Roof finish	1,093	921
9. Exterior walls	3,888	4,536
10. Interior walls	894	783
11. Stairs	1,560	1,560
12. Drywall	5,389	6,598
13. Interior doors	1,260	1,260
14. Interior finishes	4,716	5,387
15. Fittings and equipment	2,570	2,570
16. Electrical	3,000	3,600
17. Heating	3,200	3,840
18. Plumbing	2,400	2,600
Total Amounts	$ 49,842	$ 61,687
Cost per m²	498.42	429.89
Cost per sf	46.03	39.94



ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 60 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 40 M² - TOTAL 100 M²
FINISHED ATTIC (ON PONY WALL) - AREA 60 M² - TOTAL 120 M²

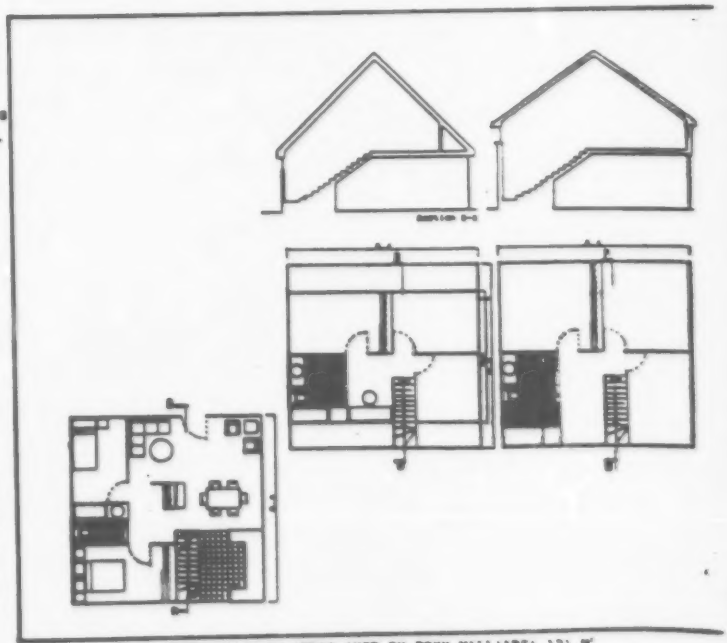
Fig 42 - Comparison (c)

Element	Two Storey House Area 121m²
1. Basement excavation	1,953
2. Foundations	1,729
3. Basement walls	7,965
4. Slab on grade	1,880
5. Upper floor construction	3,960
6. Attic construction	-
7. Roof construction	2,040
8. Roof finish	1,014
9. Exterior walls	6,552
10. Interior walls	770
11. Stairs	1,860
12. Drywall	5,817
13. Interior doors	1,470
14. Interior finishes	5,410
15. Fittings and equipment	3,310
16. Electrical	3,630
17. Heating	3,872
18. Plumbing	3,780
Total Amounts	$ 55,062
Cost per m²	463.32
Cost per sf	43.04



TWO STOREY HOUSE - AREA 121 M²

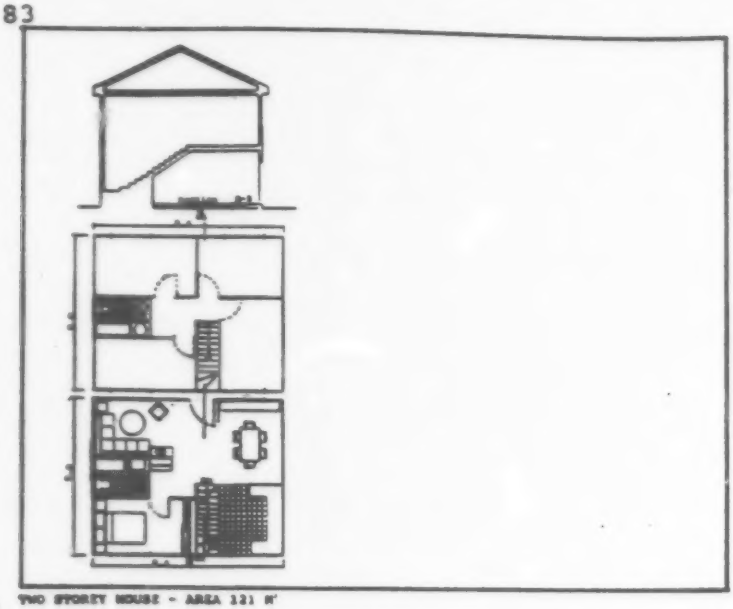
Element	One Storey House with Finished Attic Type A Truss Area 121 m²	One Storey House with Finished Attic Type D Truss Area 141 m²
1. Basement excavation	2,223	2,223
2. Foundations	1,823	1,823
3. Basement walls	8,609	8,609
4. Slab on grade	1,491	1,491
5. Upper floor construction	2,343	2,343
6. Attic construction	655	1,974
7. Roof construction	4,889	5,460
8. Roof finish	1,243	1,119
9. Exterior walls	4,608	5,472
10. Interior walls	735	777
11. Stairs	1,860	1,860
12. Drywall	5,761	6,069
13. Interior doors	1,470	1,470
14. Interior finishes	5,488	6,130
15. Fittings and equipment	3,310	3,310
16. Electrical	3,630	4,220
17. Heating	3,872	4,612
18. Plumbing	3,780	3,780
Total Amounts	$ 57,470	$ 62,322
Cost per m²	474.96	442.00
Cost per sf	44.12	41.06



ONE STOREY HOUSE WITH FINISHED ATTIC (NOT ON PONY WALL) AREA 121 M²
ONE STOREY HOUSE WITH FINISHED ATTIC (ON PONY WALL) - AREA 141 M²

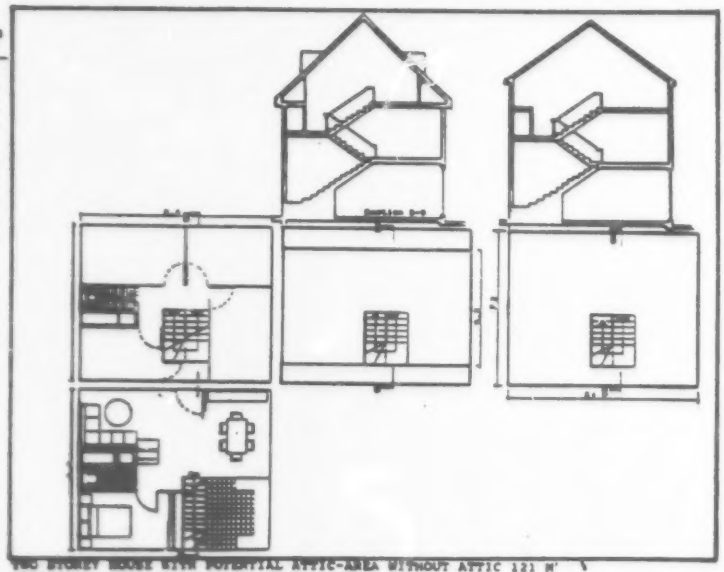
Fig 43 - Comparison (d)

Element	Two Storey House Area 121 m²
1. Basement excavation	1,853
2. Foundations	1,729
3. Basement walls	7,965
4. Slab on grade	1,260
5. Upper floor construction	3,960
6. Attic construction	-
7. Roof construction	2,040
8. Roof finish	1,014
9. Exterior walls	6,852
10. Interior walls	770
11. Stairs	1,560
12. Drywall	6,817
13. Interior doors	1,470
14. Interior finishes	5,410
15. Fittings and equipment	3,310
16. Electrical	3,630
17. Heating	3,872
18. Plumbing	3,750
Total Amounts	$ 66,062
Cost per m²	483.32
Cost per sf	43.04



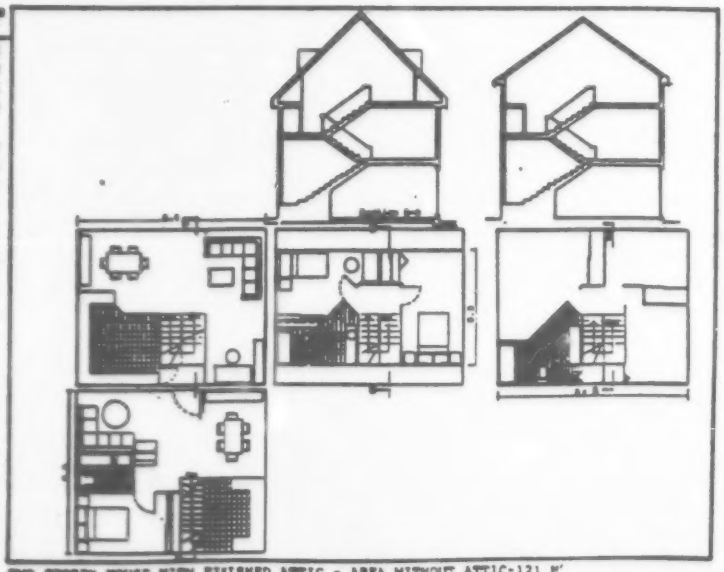
TWO STOREY HOUSE - AREA 121 M²

Element	with Unfinished Attic Type A Truss Area 165 m²	with Unfinished Attic Type B Truss Area 181.5 m²
1. Basement excavation	1,853	1,853
2. Foundations	1,729	1,729
3. Basement walls	7,965	7,965
4. Slab on grade	1,260	1,260
5. Upper floor construction	3,960	3,960
6. Attic construction	803	1,878
7. Roof construction	4,140	4,718
8. Roof finish	1,093	981
9. Exterior walls	6,948	7,056
10. Interior walls	896	896
11. Stairs	2,340	2,340
12. Drywall	7,037	7,205
13. Interior doors	1,680	1,680
14. Interior finishes	5,410	5,410
15. Fittings and equipment	3,310	3,310
16. Electrical	3,630	3,630
17. Heating	3,872	3,872
18. Plumbing	3,750	3,750
Total Amounts	$ 61,476	$ 64,194
Cost per m²	372.58	353.69
Cost per sf	34.61	33.86



TWO STOREY HOUSE WITH POTENTIAL ATTIC-AREA WITHOUT ATTIC 121 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 44 M² - TOTAL 165 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 60.5 M² - TOTAL 181.5 M²

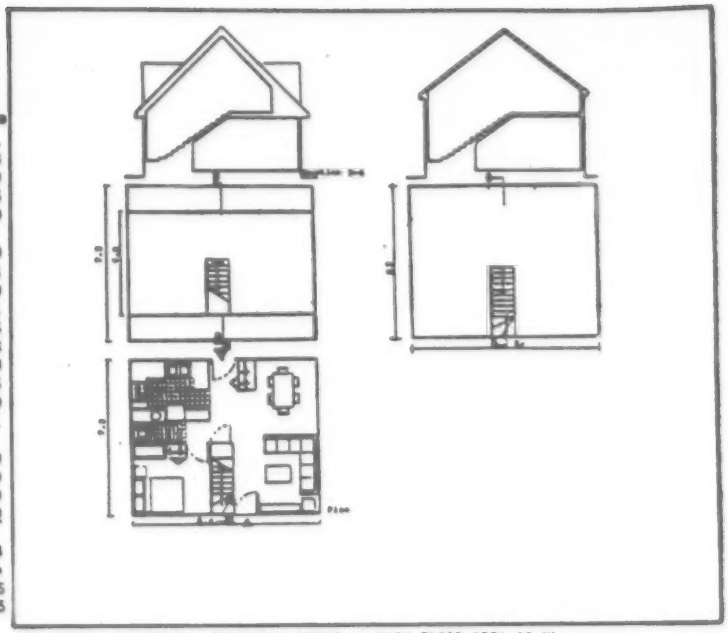
Element	with Finished Attic Type A Truss Area 165 m²	with Finished Attic Type B Truss Area 181.5 m²
1. Basement excavation	1,853	1,853
2. Foundations	1,729	1,729
3. Basement walls	7,965	7,965
4. Slab on grade	1,260	1,260
5. Upper floor construction	3,960	3,960
6. Attic construction	803	1,878
7. Roof construction	4,140	4,718
8. Roof finish	1,093	981
9. Exterior walls	6,948	7,056
10. Interior walls	1,029	1,169
11. Stairs	2,340	2,340
12. Drywall	8,033	8,723
13. Interior doors	1,260	1,260
14. Interior finishes	7,231	7,976
15. Fittings and equipment	4,684	4,834
16. Electrical	4,950	6,445
17. Heating	5,280	5,808
18. Plumbing	4,400	4,400
Total Amounts	$ 68,768	$ 74,166
Cost per m²	416.72	408.57
Cost per sf	38.71	37.96



TWO STOREY HOUSE WITH FINISHED ATTIC - AREA WITHOUT ATTIC-121 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 44 M² - TOTAL 165 M²

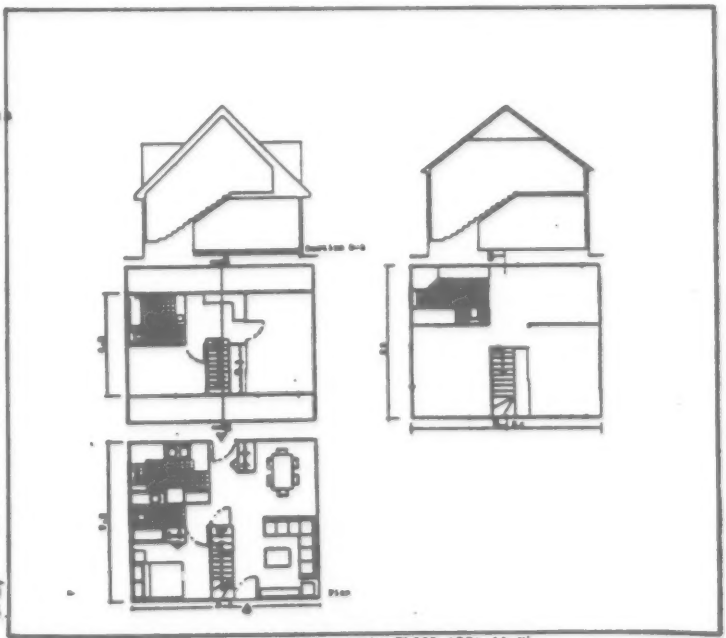
Fig 44 - Comparison (e)

Element	One Storey House with Unfinished Attic Type A Truss Area 100 m²	One Storey House with Unfinished Attic Type D Truss Area 120 m²
1. Basement excavation	1,953	1,953
2. Foundations	1,729	1,729
3. Basement walls	7,965	7,965
4. Slab on grade	1,260	1,260
5. Upper floor construction	1,980	1,980
6. Attic construction	465	1,044
7. Roof construction	4,140	3,120
8. Roof finish	1,093	921
9. Exterior walls	3,888	4,536
10. Interior walls	483	518
11. Stairs	1,560	1,560
12. Drywall	4,093	4,296
13. Interior doors	630	630
14. Interior finishes	2,681	2,681
15. Fittings and equipment	1,930	1,930
16. Electrical	1,800	1,800
17. Heating	1,920	1,920
18. Plumbing	2,200	2,200
Total Amounts	$ 41,770	$ 42,043
Cost per m²	417.70	350.36
Cost per sf	38.81	32.55



ONE STOREY HOUSE WITH POTENTIAL ATTIC - MAIN FLOOR AREA 60 M²
POTENTIAL ATTIC (NOT ON PONY WALL) - AREA 40 M² - TOTAL 100 M²
POTENTIAL ATTIC (ON PONY WALL) - AREA 60 M² - TOTAL 120 M²

Element	One Storey House with Finished Attic Type A Truss Area 100 m²	One Storey House with Finished Attic Type D Truss Area 120 m²
1. Basement excavation	1,953	1,953
2. Foundations	1,729	1,729
3. Basement walls	7,965	7,965
4. Slab on grade	1,260	1,260
5. Upper floor construction	1,980	1,980
6. Attic construction	465	1,044
7. Roof construction	4,140	3,120
8. Roof finish	1,093	921
9. Exterior walls	3,888	4,536
10. Interior walls	994	763
11. Stairs	1,560	1,560
12. Drywall	5,269	5,598
13. Interior doors	1,260	1,260
14. Interior finishes	4,716	5,387
15. Fittings and equipment	2,570	2,570
16. Electrical	3,000	3,600
17. Heating	3,200	3,840
18. Plumbing	2,400	2,800
Total Amounts	$ 49,542	$ 51,887
Cost per m²	495.42	429.89
Cost per sf	46.03	39.94



ONE STOREY HOUSE WITH FINISHED ATTIC - MAIN FLOOR AREA 60 M²
FINISHED ATTIC (NOT ON PONY WALL) - AREA 40 M² - TOTAL 100 M²
FINISHED ATTIC (ON PONY WALL) - AREA 60 M² - TOTAL 120 M²

Fig 45 - Comparison (f)

5.5 Relationship Between Cost of Attic Structures and Demand.

The foregoing cost analyses show the economic advantages of the attic truss over the regular truss.

It has been shown that while the cost of manufacturing and installing an attic truss is about twice as much as the standard lightweight truss, the average cost/m' of the units using the attic truss is significantly lower than the same cost for units with the regular lightweight truss. The analysis strongly suggests that if rather than a simple cost comparison a cost benefit analysis is carried out, as has been shown, the attic truss would always present the more economically efficient alternative.

Moreover it is important to note that costs quoted for the various attic structures by the manufacturers are based on a unique, one of a kind structure, custom designed for a specific project, wheras, the costs given for the regular lightweight truss correspond to a mass-produced, prefabricated system. With an increase in demand the cost of the attic structures will be significantly reduced.

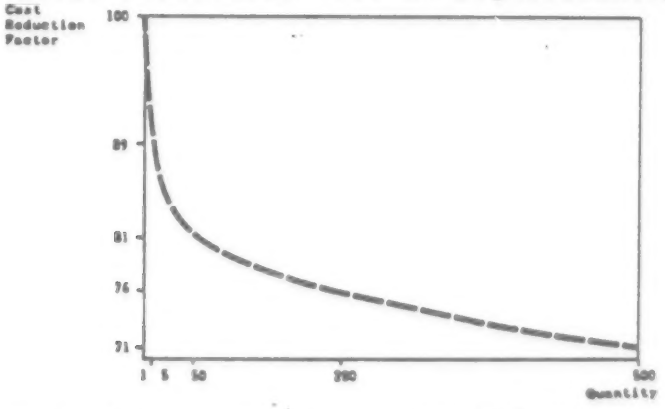


Fig 46 - Quantity vs Cost Reduction Factor

The curve presented in Fig. 46, based on figures obtained from truss manufacturers supports this argument. It shows that if the number of truss structures produced reaches the 500 level, the cost of manufacturing will drop by 30 percent. With this reduction in price, the cost of Truss A, for example, will drop from $6,900 to $4,830, and cost of truss D will fall to $5,460, with a higher volume of production. This lower cost of the attic structures, will render the cost-benefit analysis even more favourable for the attic truss as compared to the regular lightweight truss.

6. CONCLUSIONS

The study aimed to examine the efficiency of the habitable attic versus the regular roof truss and to determine suitable attic structures and their costs.

It has been shown that it is desirable to have housing units that could grow with the growth in space needs and family income and that attics could provide one of the least disruptive and least costly alternatives for accomodating this growth.

The study demonstrated that various systems, or components of systems, exist on the market that could very well provide the suitable attic structure for use in dwelling units. The technical expertise for design, as well as manufacturing and installing of these systems, are available throughout Canada. Developments in new materials, further prefabrication of components, and pre-assembly of attic systems will improve the efficiency of these systems.

The economic analyses carried out, determined that it is less costly to provide for expansion in an attic space than to build an on-grade addition. It was also shown that in a bungalow it would cost almost 50% less to provide accomodation in an attic area (both initial cost and finishing costs included), than to provide the same accomodation in the main floor. By comparing costs/m^2 of units using an attic structure and units using the regular truss it was shown that the attic truss is always, by far, the more economically efficient alternative.

Two attic systems were used for this cost analysis, the attic truss with the integral floor and the scissor truss on pony walls which met the architectural, structural and environmental conditions required for a habitable attic and were also suitable in terms of costs. The scissor truss on pony walls was the more economically efficient system, since the cost/m' of habitable area for this system was lower in all cases.

It has been argued that, although the cost of the regular lightweight truss is lower than the cost of the attic structures, if the cost of the roof truss is considered as a percentage of total construction cost and is compared to the habitable area provided by the attic truss, then the economic decision would be to use the attic truss.

Moreover, it was shown that with the increase in demand the cost of the attic trusses would be reduced to about 70% of the present cost, making the attic alternative an even more suitable choice.

Architectural trends and the acceptance of high-pitched roofs and dormer windows indirectly influence demand and can result in the incorporation of attics as parts of the habitable volume of dwelling units. This trend was observed in Montreal, Toronto, and Vancouver, where due to preference for certain architectural styles, attic living has been revived to a certain extent. The same trends could continue more strongly and emerge in other parts of the country.

In large scale, single family residential developments on small lots, where horizontal expansion is not possible due to lot configuration, and vertical expansion is not permitted due to height regulations, the potential for the acceptance of the habitable attic is greatest. If, instead of the standard truss the attic truss is used in these developments, the possibility of expansion, even in very small units, will be provided for. This possibility will be an added advantage and a selling point for small units which usually do not allow for any future expansion.

The greater slope provided by the attic truss is also more suitable for the heavy rain and snow fall prevalent in many parts of the country as well as for installation of solar panels.

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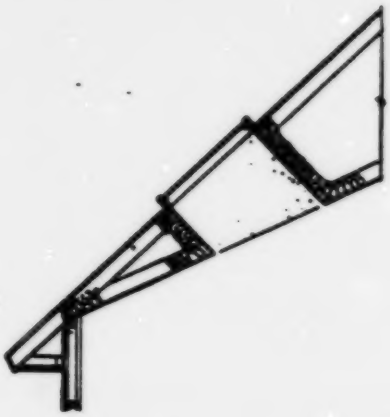
APPENDIX 1

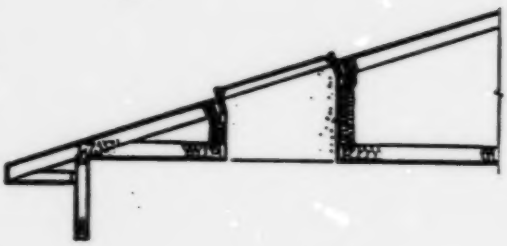
Developments in Skylights and Dormer Windows

During the last decade, developments in the production of skylights and dormer windows have made it possible to provide sufficient lighting to almost any type of attic space. Some examples of these possibilities are presented in the following drawings. A-1-1 to A-1-3.

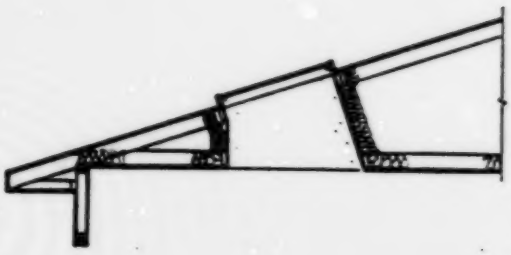
SHAFT PERPENDICULAR TO ROOF PITCH



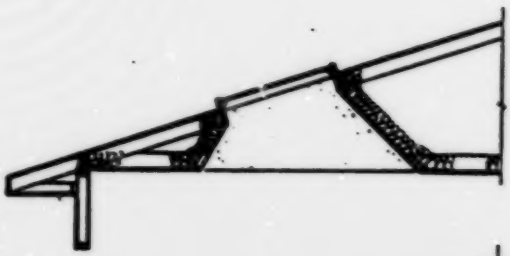
SHAFT PERPENDICULAR TO CEILING

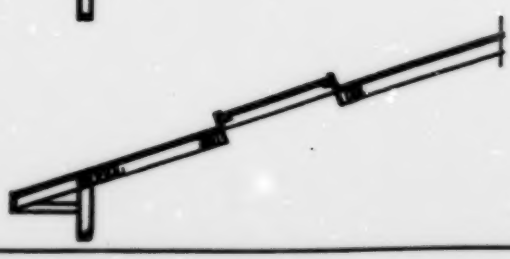


SHAFT COMBINATION



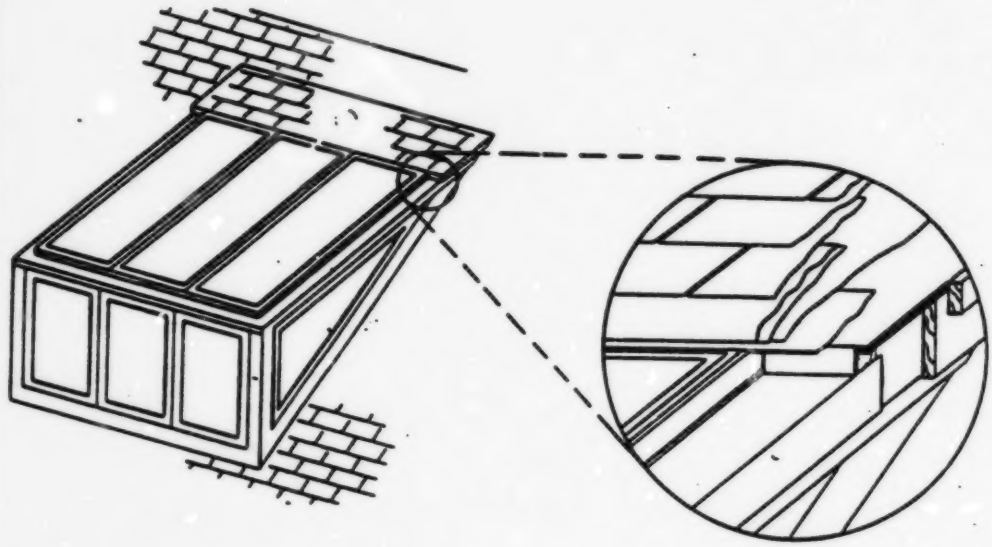
COFFERED SHAFT (FLARES OUT ON ALL SIDES)

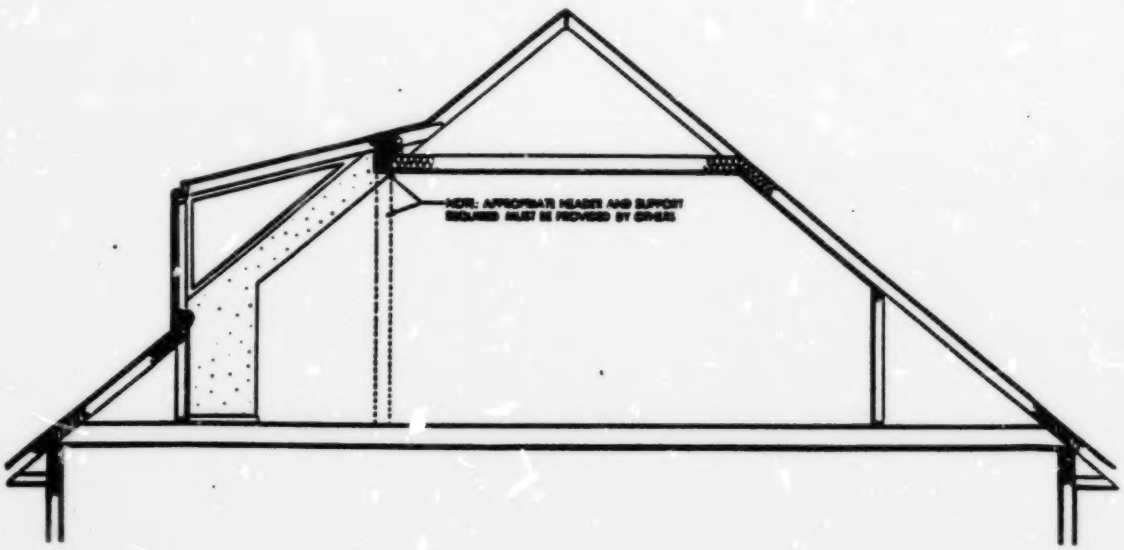




A.1.1

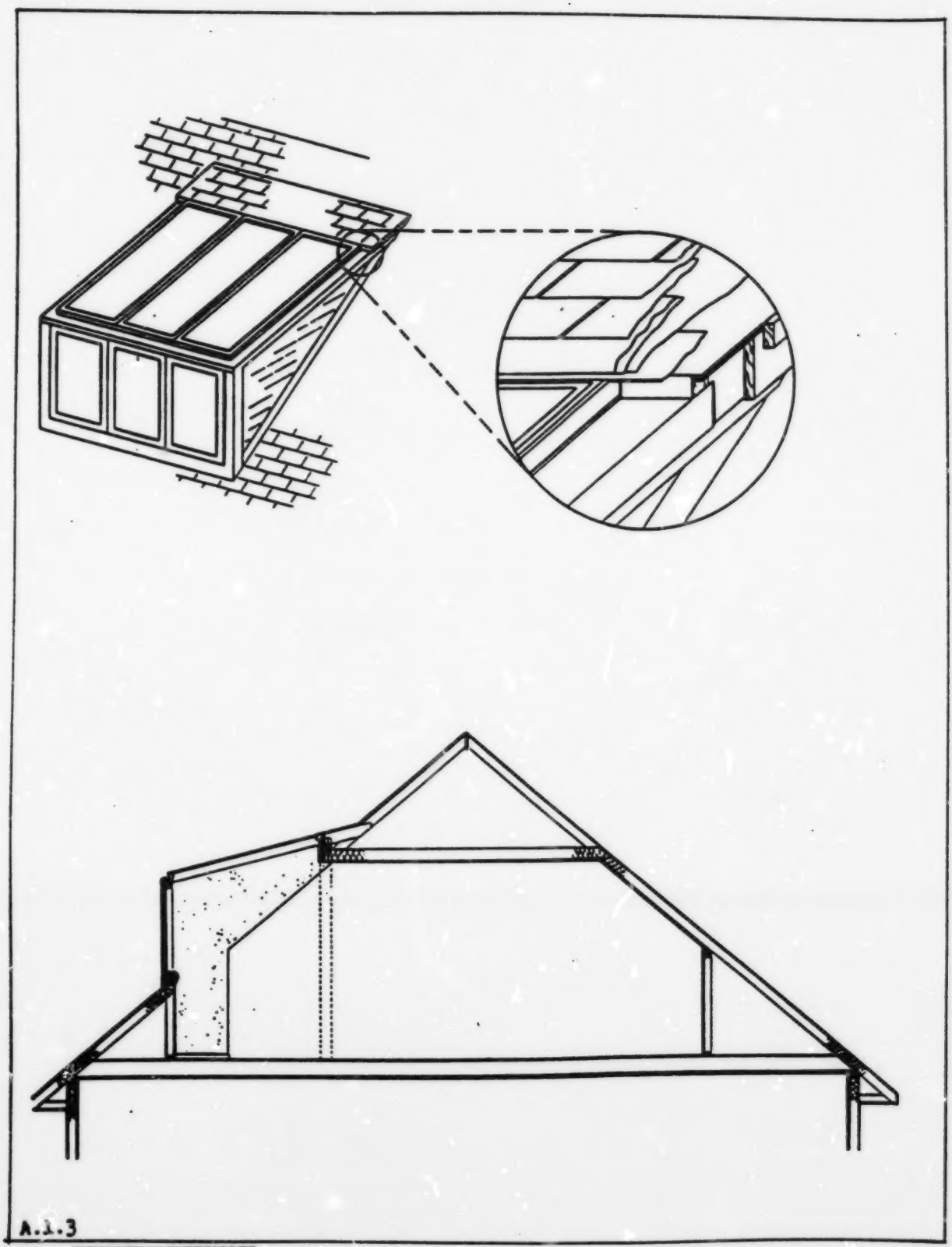
SKYLIGHT OPTIONS





A.1.2

DORMER
With Glazed Clad Frame Triangles

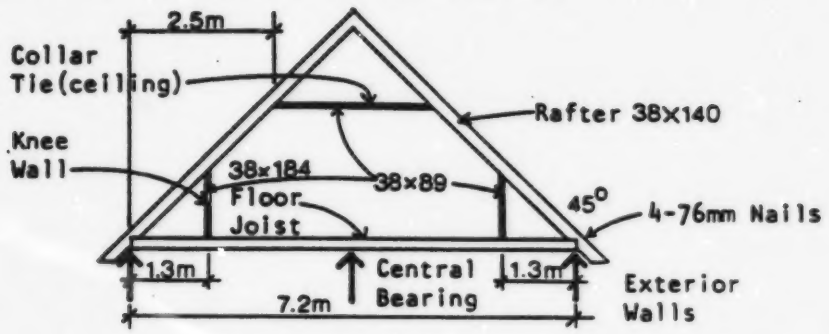


A.1.3

DORMER — ALTERNATE
With Conventional Side Wall Construction

Traditional Attic Construction Methods

Traditional Attic Conforming to NBC Part 9.



1. GEOMETRY
   - building width = 7.2 m
   - roof slope 45°
   - bearing at centre of bottom chord of truss
   - spacing 400 mm o.c.

2. LOADS
   a) Dead load: - 0.6 kN/m^2 typical
   b) Live load: -
   c) Snow load: - choose typical ground snow load for Canada. Taken from MBC Climatic Information.

Major cities:		
	Halifax	2.2 kN.m^2
	Charlottetown	3.3
	St. Johns	3.5
	Fredericton	3.1
	Quebec	3.8
	Montreal	2.7
	Toronto	1.8
	Ottawa	2.9
	Winnipeg	2.1
	Saskatoon	1.5
	Calgary	.9
	Edmonton	1.5
	Vancouver	1.9
	Average	2.4 kN/m^2
	Use	2.5 kN/m^2

Snow load factors. (Taken from NBC Supplement)

Case I snow right across roof	S = 1.25 kN/m^2
Case II partial snow load	S = 1.56 kN/m^2

d) Occupancy load:
Attic liveload = 1.4 kN/m^2

3. MATERIAL
Consider SPF #2 and better.

4. FORCES AND MEMBER STRESSES
The forces in the members and connectors were found by analyzing the truss shown as a simpler plane frame computer programs utilizing the stiffness approach.

a) Tie:
i) Worst combination for axial and bending
Axial force - 2.21 kN
Bending moment - 1.14 kNm

Max Stress = .0047 kN/mm^2
allowable = .0065 (1.15) (1.15) = .0086 ok

ii) Worst shear 1.42
Max stress = .00030 kN/mm^2
allowable = .00046 (1.15) (1.15) = .00061 ok

b) Rafter:
i) Axial force = 2.20 kN
Bending moment = .80 kNm

Max stress = .0053 ok

ii) Shear = 1.14 kN

Max stress = .00032 ok

c) Connections:
Tie/Rafter Connection

force = 2.77 kN

82 mm nails N = .260 (.8) 1.15) = .240
No. req'd = 2.77/.240 = 11.5 use 12 nails
No. provided = 4 - 76 mm nails

Similar force in collar tie connection.

APPENDIX 3

Details of Cost Analysis

A.3.1 Cost of Alternative Roof Structures

Obtaining of costs for the alternative roof structures described in Sections Four and Five was carried out through contacts with manufacturers and builders in Eastern Canada as well as in British Columbia. Drawings of the various attic systems together with roof slope, span and length of truss, as well as design loads, were supplied to the manufacturers. The same procedure had been carried out in May, 1988 and those cost estimates for the systems were also available.

For the most common systems, such as A, B, D, and E, it has been possible to get estimates from manufacturers both in Eastern and Western Canada. For some of the other less common systems obtaining of costs has been somewhat problematic. When manufacturers did not have much previous experience in the production of an attic structure, they were either reluctant to give any cost estimates or gave estimates which were much higher than the other manufacturers' prices, to cover any unforseen costs. In some other cases the cost estimate given for a system by one manufacturer was much lower than the other estimates which could either be due to lack of experience or intended to promote a product.

Cost figures given in table A.3.1., are based on the average of estimates received from the various sources, ommitting in each case, the figures which were either much higher or much lower than the other estimates for a system. This procedure will not affect the total outcome of the evaluations presented in Section Five.

Cost of Alternate Roof Structures $ Canadian - March 1989
Dimensions: 8.4 span x 11.9 length - foot print 100m^2

	Structure	Installation of Structure	Sheathing & Flooring	Insulation air/vapour barrier	Total	Total (Rounded)
Regular Truss 6/12	1,090	580	850	860	3,380	3,400
Regular Truss 12/12	1,180	740	1,110	860	3,890	3,900
Cut Roof	1,680	1,820	2,210	1,360	7,070	7,100
A. Truss with integral floor	3,260	1,160	1,110	1,360	6,890	6,900
B. Truss without integral floor	2,240	1,160	2,210	1,360	6,970	7,000
C. Gambrel Truss without integral floor	3,100	1,730	2,300	1,480	8,610	8,600
D. Scissors Truss (on pony walls)	2,370	1,270	2,610	1,530	7,780	7,800
E. Truss with integral pony wall	3,390	1,290	2,300	1,440	8,520	8,500
F. Plywood web rafters	3,440	1,040	2,410	1,360	8,250	8,200
G. Steel pipe truss rafters	3,400	1,160	2,410	1,360	8,330	8,300
H. Flat laid 2 x 4 truss rafters	3,580	1,160	2,410	1,360	8,510	8,500
I. Laminated veneer lumber		1,160	2,410	1,360		
J. Parallel strand lumber		1,160	2,410	1,360		
K. Stressed skin plywood panels	4,620	1,580	1,300	-	7,500	7,500
L. Plywood "I" beams with integral rigid insulation	6,050	1,580	2,410	-	10,040	10,000

TAble A.3.1 cost of Alternate Roof Structures

NOTES:

1. Trusses

Prefabricated/manufactured roof trusses at 600 mm o/c. for a gable end roof framing system with an 8.40 span and 12:12 slope (45°) for a 100 m^2 floor plan.

2. Installation - of trusses (21 No.)

3. Structure

Comprises cut roof rafters etc. in lieu of trusses, 12 mm plywood roof sheathing, attic floor joists (38 x 235 at 400 mm o/c), and pony wall supports (38 x 89 mm) where not an integral part of truss.

4. Insulation and air/vapour barrier

Comprises R28 batt insulation and 4 mil. vapour barrier generally to underside of sloped roof, except for gang nail trusses where it is installed at ceiling level.

A.3.2 Specifications

1. Basement Excavation
   - Backfill excavated material
   - Surplus disposal offsite

2. Foundations
   - Concrete footings - 450 X 150 mm
   - Reinforcing steel - 2/20m bars
   - Dowels - 20m bars
   - Weeping tile 100 mm diameter and granular backfill

3. Basement Walls
   - Concrete - 200mm
   - Reinforcing steel - 15kg per m^2
   - Damproofing - 2 coats/sprayed bituminous compound
   - Insulation - 50 x 1200 rigid polystyrene

4. Slab-on-Grade
   - Concrete - 100 mm
   - Poly vapour barrier - 6 mil.
   - Granular sub-base - 150 mm

5. Upper Floor Construction (including balcony roof decks)

   - Fir joists 400 mm on centre - 38 x 235 mm

6. Attic Floor Construction

   - Joists integral with roof trusses 600 mm on centre
   - Bridging 2.40 m on centre - 38 x 38 mm
   - T & G plywood sheathing - 19 mm

7. Roof Construction and Insulation

   - Trusses 600 mm on centre
   - S.E. plywood sheathing - 12 mm
   - R28 Batt insulation
   - 4 mil poly vapour barrier

8. Roof Finish (including balcony roof decks)

   - Building paper 15#
   - Asphalt shingles 210#
   - Soffit and fascia - aluminum
   - Balcony roof deck - rubberized asphalt membrane roofing

9. Exterior Walls (including gable ends and balcony walls)

- Fir studs at 400 mm on centre - 38 x 89 mm
- Fir plates - 3/38 x 89 mm
- S.E. plywood sheathing - 12 mm
- Building paper
- Standard vinyl siding
- R12 batt insulation
- 4 mil poly vapour barrier

10. Interior Walls

- Fir studs at 400 mm on centre - 38 x 89 mm
- Fir plates - 3/38 x 89 mm

11. Stairs

- Standard softwood stringers - 38 x 235
- Plywood risers - 19 mm
- Softwood treads - 38 x 235 and 38 x 38

12. Drywall to Walls and Ceilings

Finished attic space

- Gypsum drywall taped and finished 12 mm
- Paint finish to wall and ceilings
- Carpet to bedroom and living room, VAT to kitchen
- Ceramic tile to walls above bathtub
- Ceramic tile floor to bathroom
- Hollow core wood doors with wood frames and trim, paint finish
- Bi-fold sliding closet doors, closet shelf and rods
- Standard quality hardware
- Standard quality vanity cabinet, wall mirror and towel rack
- Standard electrical fit out for 3 bedrooms, 2 bathrooms, 2 kitchens, living rooms and dining areas
- Gas fired forced air heating system
- Bathroom fixtures, complete with hot and cold water, waste and vent pipe.
- Kitchen cabinets and plumbing

A.3.3. Pricing

The unit prices used are generally in accordance with the CMHC 1987 Labour and Materials Survey undertaken by Barnett Treharne Yates Ltd. They are for single detached houses in a Vancouver location. A 10% factor cost escalation from July 1s to January 1989 has been included.

Truss prices are as per quotations received from suppliers in January 1989 for the lower mainland (Vancouver) and based on the following design criteria:

- Dead load 0.6 km/m^2
- Live load 1.9 km/m^2
- Snow load 1.25 km/^{2} right across roof. As we understood from suppliers that differential loads are not normally considered for single family residences.

The partitions in the attic area have been measured full height i.e. 2.44, although the average height is approximately 1.66. This over measurement allows for the additional cutting and waste required.

Appendix 4

An example of shop drawings for a habitable attic truss is shown in the following page.

The drawings have been reduced to obscure technical information. They are presented here only as an example of the types of drawings prepared by the manufacturers on the basis of project characteristics.